STREAM ENHANCEMENT GUIDE

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1. PREFACE

The Salmonid Enhancement Program is a diversified federal-provincial program aimed at restoring our salmon and sea-run gamefish to their historic levels of abundance. Diversity is assured by addressing a range of public interests in salmonids, and by working towards a balance of natural, semi-natural and artificial enhancement projects.

From the outset of the program the protection and improvement of salmon and trout streams were declared goals, and it soon became apparent that some documented account of various methods would be of value. This was needed both to instruct fisheries staff, who might have limited experience in applying techniques of stream enhancement, and to encourage and assist organized public groups in their involvement with streams. The present guide is the outcome of this need.

In any efforts directed at streams, habitat protection and maintenance must take priority. Emphasis, initially, should be placed on correcting and preventing watershed problems; improvements can then be undertaken where opportunities exist. This approach is reflected in the sequence of the guide.

Public users of the guide will note that some techniques are highly technical (e.g., fishways) and should not be attempted without considerable advice from experienced fisheries staff who have access to detailed professional information. They may also find that the procedures to obtain project approval from various agencies are initially discouraging. These difficulties should lessen, however, as Community Advisors, appointed to each region minimize this process.

Comments by users of the guide are welcomed. These will be considered in the preparation of a second edition that will incorporate new knowledge acquired throughout the Pacific Northwest. In addition, a shortened, simplified, version will be written for newcomers to stream enhancement.

Salmonid streams are unique ecological systems that can provide a wealth of educational, recreational and socio-economic benefits in British Columbia. It is our belief that this guide, as part of the Salmonid Enhancement Program, will bring a greater realization of these benefits.

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To the many others who assisted, we extend our thanks.

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5. INTRODUCTION

The anadromous salmonid populations of British Columbia depend on some 1800 stream systems for their reproduction and freshwater rearing. Though these streams remain the backbone of salmon and sea-run trout production in this province, the pressures of industrial and urban development have degraded much of the habitat, thereby contributing to the overall decline from historic salmonid population levels. The governments of Canada and British Columbia have thus embarked on a long-term program to enhance the salmonid resource, including a commitment to enabling public participation. The major opportunity for such participation lies in maintaining, restoring and improving the stream habitat essential to salmonid production.

This guide provides an introduction to the various approaches and methods suitable for stream enhancement in British Columbia. It has been prepared to assist both the interested public and government agency staff, having limited technical background in this field, to plan and implement projects. Because the subject is complex, it should be recognized that a publication such as this cannot substitute for the first-hand assistance of experienced advisors.

For the purposes of this guide, we have defined stream enhancement as *restoring, protecting and improving the capability of streams to produce anadromous salmonids.* The focus is on methods best suited to the smaller streams, which frequently offer the greatest potential for enhancement (Fig 5.1). As their contribution to salmonid production has often been underestimated, small streams have been highly vulnerable to environmental degradation, particularly near centres of population.

Through public participation, enhancement projects offer a unique opportunity to develop within the communities of the province a greater awaremess of the salmonid resource and man's influence on the stream environment.

Figure 5.1 A typical small coastal stream with a diversity of habitat for salmon and trout.

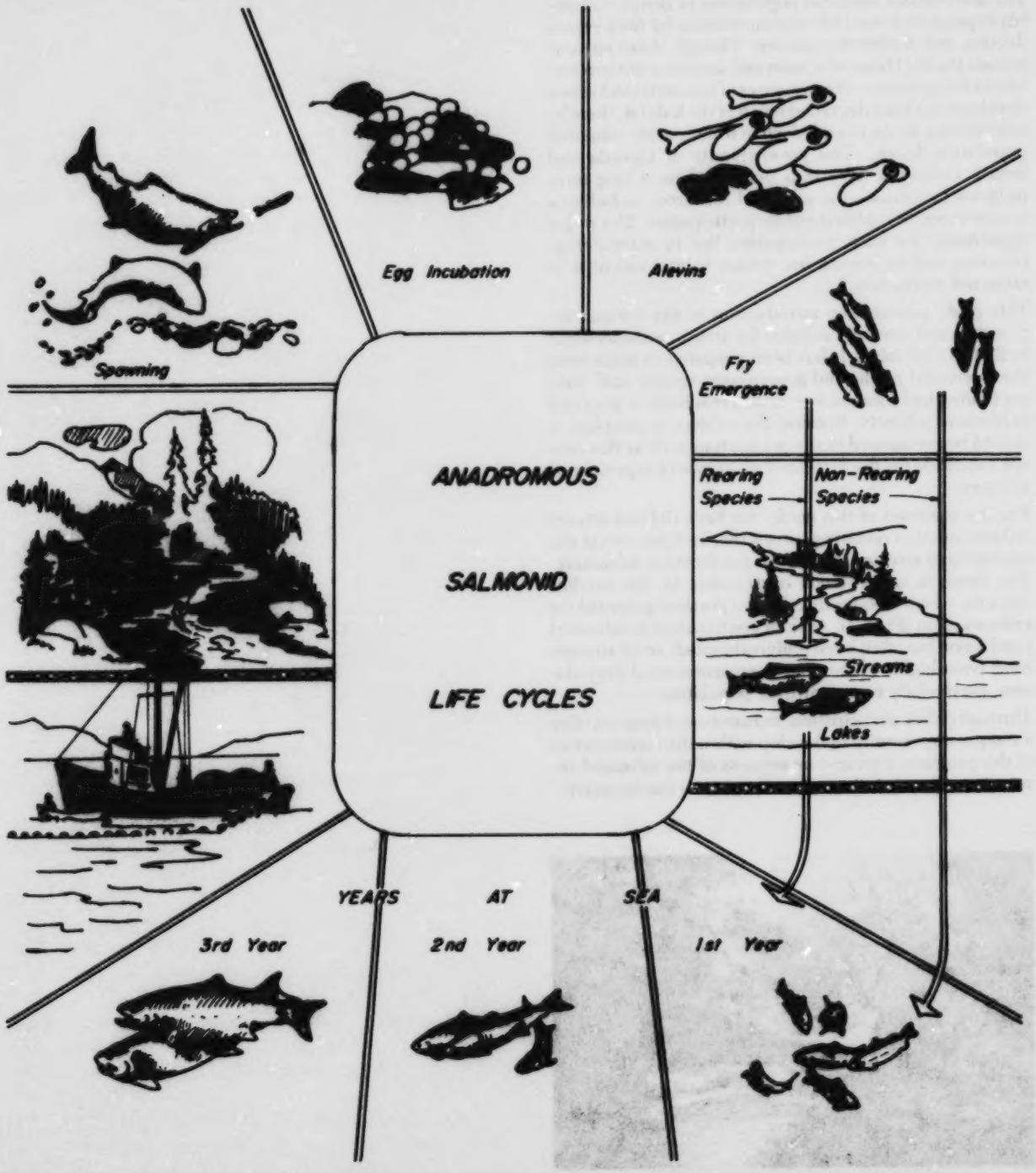


Figure 6.1 *The anadromous salmonid life cycle, showing difference between those species with a juvenile rearing phase in freshwater (coho, chinook and sockeye salmon; steelhead and cutthroat trout, Dolly Varden) and those which migrate directly to sea following emergence (chum and pink salmon). Time spent in freshwater and saltwater varies between species and stocks.*

6. THE ANADROMOUS SALMONID RESOURCE

Anadromous fish utilize the ocean for a major portion of their growth, but depend on freshwater for reproduction. The streams of British Columbia support eight anadromous fish species of the Family Salmonidae: five species of Pacific salmon (coho, chinook, chum, sockeye and pink), two species of trout (steelhead and cutthroat), and the Dolly Varden char. Each of these species is unique with respect to its life cycle and habitat requirements in the freshwater phase. Understanding their specific requirements, and the factors limiting their production, is essential to developing effective enhancement projects.

Perhaps the most significant characteristic of anadromous salmonids is their habit of returning from the ocean to spawn in their natal streams, where they were spawned and reared. This *homing* characteristic enables the development of distinct and separate stocks or populations, each adapted to the particular conditions of its natal stream. One of the more obvious manifestations is the difference between populations in the seasonal timing of adult migration and spawning in freshwater.

Salmonid Life Histories

All species of anadromous salmonids require a freshwater environment for spawning and embryonic development, but the species differ in the extent to which they rear in freshwater after emerging from the gravel as fry. Pink and chum salmon, for example, migrate to sea immediately following emergence, whereas the other species may rear in streams, lakes or estuaries for periods of months to several years before entering saltwater. Typical life cycles are shown in Fig. 6.1 and a guide to identification of adults and juveniles is presented in Appendix B.

There are significant differences in the life histories of three genera, the Pacific salmon *(Oncorhynchus)*, the trout *(Salmo)* and the char *(Salvelinus)*. While Pacific salmon invariably die after spawning, trout and char may survive to spawn more than once. Salmon and char characteristically spawn in the fall, on declining temperatures, but trout spawn in winter or spring, generally on a rising temperature regime.

All species use the gravel bottom of streams or upwelling groundwater sources for spawning. The spawning nest or *redd*, which is constructed by the female, consists of a series of pockets in the gravel in which the fertilized eggs are deposited to a depth of 20 to 50 cm. Development of the embryo goes through the *egg* stage to hatching, then through *alevin* development to full absorption of the yolk sac and subsequent emergence of *fry* from the gravel (Figs. 6.2 and 6.3). The period from spawning to fry emergence may range from as little as 2 months in the case of spring-spawning trout, to as much as 9 months for those Pacific salmon populations spawning in the colder streams, where temperatures close to 0°C prevail through most of the winter. In the latter case, spawning would likely occur in early to mid-September, eggs would reach the *eyed* stage (when the eyes, head and body form of the embryo first become apparent) during October, hatching would occur in the following March and April, and the fry would emerge during May.

With the exception of the coastal cutthroat trout and the Dolly Varden char, British Columbia's anadromous salmonid species undertake extensive feeding migrations in the Pacific Ocean, between northern California and the Gulf of Alaska. They are found at distances up to 1600 km off shore. Some coho salmon, however, remain in coastal waters such as Georgia Strait throughout their marine life.

***Figure 6.2** Eyed salmon eggs (upper) and a salmon alevin (lower) immediately after hatching from the egg.*

Coho Salmon

Coho salmon *(Oncorhynchus kisutch)* are the most adaptable of British Columbia's five salmon species. Coho spawn in virtually all coastal rivers and creeks accessible to them. In the Fraser and Skeena river systems, they are also known to migrate and spawn as much as 500 km from the sea.

In southern British Columbia the majority of coho salmon mature after 3 years of life, having spent 1 year as juveniles in freshwater and 2 years in the ocean. In colder systems and in northern areas, the freshwater rearing phase is commonly 2 years. A portion of the spawning run

is comprised of *jacks*, precocious males which mature after only one summer of ocean life and weigh in the order of 0.5 kg.

Mature coho salmon generally migrate into streams during September to November, and spawn over the period mid-October to mid-December, with some spawning as late as February. Though mature fish of 14 kg have been recorded, coho most commonly weigh 2.5 to 5.5 kg at maturity. The fecundity, or number of eggs carried per female, ranges from approximately 2500 to 5000. Coho fry emerge during April and May, and attain most of their subsequent freshwater growth on a diet of aquatic and terrestrial insects. Seaward migration takes place in May and June, one or more years after fry emergence. The seaward migrants, known as *smolts*, generally measure 8 to 12 cm long at the time of migration. In some cases, coho smolts prey intensively on the fry of pink, chum or sockeye salmon which are migrating at the same time.

Chinook Salmon

Chinook or *spring* salmon *(Oncorhynchus tshawytscha)*, the largest of the Pacific salmon, generally utilize the larger rivers. Certain races of chinook migrate farther upstream to spawn than other anadromous species, eg. above Prince George on the Fraser system and in the upper Yukon River, up to 2900 km from the sea.

The extent to which chinook salmon rear in freshwater and the length of their ocean residence varies from one population to another. In southern, coastal populations, chinook juveniles tend to rear for only 2 to 3 months in the natal stream or estuary before entering the ocean. In the colder streams and more northerly rivers, juvenile chinook rear in freshwater for one full year. Age at maturity is generally in the range of 2 to 7 years, with the majority maturing after 3 to 5 years in the ocean.

Timing of spawning migration also varies greatly among chinook salmon. Populations which spawn in streams distant from the sea, in major systems such as the Fraser, may start their migration into that river as early as May or June even though they do not spawn until September. Coastal populations generally enter the spawning stream in September or October, within one month of spawning.

Chinook are known to reach a size of over 40 kg at maturity, but the majority mature at a weight of 7 to 12 kg. Fecundity, which is related to fish size, is generally in the range of 4,000-6,000 eggs. Chinook salmon fry emerge during March and April. Populations which reside in the stream for only 2 to 3 months migrate to sea by July, at a length of 6 to 9 cm. Populations which tend to spend one year in freshwater after emergence undertake their seaward migration in April or May, at a length 8 to 10 cm. In freshwater, juvenile chinook feed mainly on aquatic insects.

Sockeye Salmon

Sockeye salmon *(Oncorhynchus nerka)* normally utilize a lake environment for juvenile rearing prior to seaward migration. The major sockeye populations in British Columbia therefore occur in the large lake systems of the Fraser, Skeena, and Nass rivers, and at Rivers and Smith inlets on the central coast.

Mature sockeye enter these river systems between June and September. The races which spawn farthest from the sea generally enter the rivers earliest. Spawning occurs in September and October, in either lake inlet streams or at lake outlets. Certain populations spawn along the lake shorelines, in groundwater-fed deposits of gravel. Sockeye fry emerge from the gravel in April and May, and migrate directly to a lake. Here they usually rear for 1 year before migrating to sea as smolts, averaging 6 to 10 cm long. During their year of lake residence sockeye juveniles feed mainly on zooplankton.

Most sockeye spend 3 or 4 years in the ocean before reaching maturity at a total age of 4 or 5 years. Size at maturity, which varies with the population, is in the range of 2 to 5 kg. Fecundity, which also varies between populations, is generally between 2500 and 4500 eggs.

Pink Salmon

Pink or *humpback* salmon *(Oncorhynchus gorbuscha)* are the most abundant of the five salmon species in British Columbia. Although pinks are distributed more widely

***Figure 6.3** Differences in body form and markings of emergent salmon fry. Chum fry (upper) migrate to sea immediately after emergence, whereas coho fry (lower) rear in fresh water for one or more years before seaward migration.*

than sockeye, a few major river systems account for most of their production. Pink salmon are found mainly in the coastal rivers. They enter freshwater shortly before spawning, which occurs in most areas during September and October. Because of their invariable two-year cycle, pink salmon populations spawning in the odd-numbered years do not interbreed with those spawning in the even years. In a given geographic area either the odd-year or even-year population tends to predominate, and in some cases one population may be absent.

Usually weights of mature pink salmon are in the 1.5 to 2.5 kg range. Fecundity, which is related to female size, is about 1500 to 1900 eggs.

Pink salmon juveniles have no freshwater rearing requirement. Following emergence from the gravel in April and May, pink fry migrate downstream to inshore marine areas, where they rear until mid-summer before moving out to sea.

Chum Salmon

In British Columbia, chum or *dog* salmon *(Oncorhynchus keta)* spawn only in coastal streams, generally within a few kilometres of saltwater. Chum salmon are present in most coastal streams, and next to coho they are the most widespread.

Adults enter streams just prior to spawning, which may take place as early as August in northern areas. In southern British Columbia, time of spawning varies considerably between populations, occurring over the period October to January. Chum salmon fry emerge from the gravel in April and May and migrate directly to sea. Like pink salmon, they appear to have little or no freshwater rearing requirement. But in rivers such as the Fraser, where migration distances are relatively long, a portion of the fry population is known to feed during seaward migration, putting on modest growth before reaching saltwater.

The majority of chums mature at 3 to 5 years of age, and at a weight of 3.5 to 5.5 kg. Fecundity of a population is likely to be about 3,000 to 3,500 eggs.

Steelhead Trout

The steelhead *(Salmo gairdneri)* is the anadromous form of the rainbow trout. Steelhead populations occur in most accessible coastal streams, and also migrate up to 500 km from saltwater to spawn in the Fraser and Skeena river systems.

Steelhead are known to enter spawning streams at every month of the year. Migration timing differs considerably between populations, which are usually categorized as *winter-run* (November to May) or *summer-run* (June to October). The time of spawning also varies from one population to another. It may occur as early as January and as late as June, being later in the colder rivers. Because steelhead spawn during a period of rising temperature, the period of embryonic development is short relative to that of salmon. Steelhead fry generally emerge in June or July, and rear for either 2 or 3 years in the natal stream or in a lake before migrating to sea as smolts of 14 to 20 cm long, during April to June.

Steelhead most commonly spend either 2 or 3 years in the ocean before returning to spawn for the first time. Though many combinations of freshwater and saltwater age are known to occur, the majority of steelhead are 4 to 6 years old at first spawning. Mature fish weigh in the 3 to 8 kg range. Fecundity is about 3,000 to 4,000 eggs. Only a small proportion of each steelhead population, mainly female fish, survives to spawn a second or third time. The proportion of repeat spawners has been found to vary between populations, from 5 to 30 percent, and averages about 10 percent.

Cutthroat Trout

Coastal cutthroat trout *(Salmo clarki clarki)* are widely distributed in the coastal streams and lakes of British Columbia, and are not known to migrate far inland from the sea. Cutthroat streams tend to be of smaller size and lower gradient than those which support steelhead, and frequently have extensive slough areas in the lower reaches. The life history of cutthroat in British Columbia is complex and has not been studied in detail. In southern areas, the majority of juveniles rear for 2 or 3 years in the stream before migrating to saltwater at an average length of about 18 cm. Cutthroat spend 1 or 2 summers in the ocean before returning to spawn for the first time. While in the ocean, cutthroat remain in coastal areas, generally within 10 km of their natal stream. They tend to feed in shallow areas near shore.

Mature cutthroat migrate into spawning streams during the fall, principally from October to December. Spawning takes place in the January to March period. Mature fish average approximately 0.8 kg in weight, and range from 0.5 to 2 kg. Average fecundity varies between populations, from 800 to 1500 eggs. Repeat spawning, as in the case of steelhead trout, is also suspected to occur.

Cutthroat fry emerge in June and July. Following emergence, juvenile cutthroat feed principally on aquatic and terrestrial insects. In rivers with runs of pink, chum or sockeye salmon, adult cutthroat are know to feed on both the eggs and the newly emerged fry of these species.

Dolly Varden

Dolly Varden char *(Salvelinus malma)* occur throughout British Columbia. Coastal populations are generally anadromous, whereas interior populations are not. The life history of anadromous Dolly Varden in British Columbia, and the extent of its variation has received very little study to date.

Anadromous Dolly Varden migrate into rivers in late summer or fall, and spawn during October and November. Age at sexual maturity is 4 to 6 years. The fall migration may also include sexually immature fish which overwinter in freshwater after having spent only one summer in saltwater. Dolly Varden juveniles spend 2 to 4 years in freshwater prior to entering the ocean.

Adult Dolly Varden are known to be predators in freshwater. Adults follow salmon runs upstream during the fall, and feed on loose eggs that drift from spawning areas. Migrating salmon juveniles, both fry and smolts, are also a

common food source for Dolly Varden in the spring.

The Stream Ecosystem

A stream's physical and chemical characteristics reflect the character of the land area which it drains. The steepness of its gradient is related to the drainage topography. The composition of the stream bed is also a product of that gradient, as well as the erosional force of high discharges and the susceptibility of the underlying materials to erosion. In streams where gradient or discharge are high, rock and gravel predominate in the stream bed. Finer particles are swept away at high discharges. Where gradient or discharge are relatively low, sand and silt tend to accumulate.

From headwater to mouth, streams commonly pass through a gradual transition from higher to lower gradient, and the stream valley becomes less confined. With this transition, the stream bottom materials become smaller, the banks become lower, the channel width and the occurrence of side channels tends to increase, and pools occur at less frequent intervals. Though the spawning and rearing requirements of anadromous salmonids are diverse, they depend for the most part on stream areas of high to intermediate gradient, with a predominance of rocks, boulders and gravel.

During their freshwater rearing phase, salmonid juveniles feed mainly on the larvae of aquatic insects and, to a lesser extent, on terrestrial or land-based insects. The food web leading to these insects is extremely complex with many links and pathways, all connected to the surrounding land (Fig. 6.4). Organic material and the dissolved nutrients essential for algal production, such as phosphorus and nitrogen, enter streams from the land. These materials provide the basic energy for the food chain leading to salmonid fishes. The vegetation in the watershed, particularly the trees along stream banks, is an important contributor to this ecosystem.

Aquatic insects generally comprise the major food source for stream salmonids. Certain of these insects, eg. the stonefly *(Plecoptera)*, are commonly carnivorous, feeding mainly on other insects. However, the aquatic insects most important to juvenile salmonids, eg. true flies *(Diptera)* and mayflies *(Ephemeroptera)*, are generally herbivorous. These insects graze on algae, which grow on the rocks of the stream bed. They also graze on decaying leaves, and on colonies of bacteria and fungi which establish on decaying organic matter such as leaves and needles of coniferous trees. Examples of these aquatic insect groups are shown in Fig. 6.5.

Although juvenile salmonids on occasion obtain insects directly from the stream bottom, the insects become available mainly as *drift*. Terrestrial insects usually present themselves by accident, often falling on to the water surface from streamside vegetation. Aquatic insects, on the other hand, have a natural tendency to leave their positions among the boulders and gravel of riffles, and drift downstream for a short distance before reattaching to the stream bottom. This drift occurs mainly at night. In any given 24-hour period, a small portion of the insect

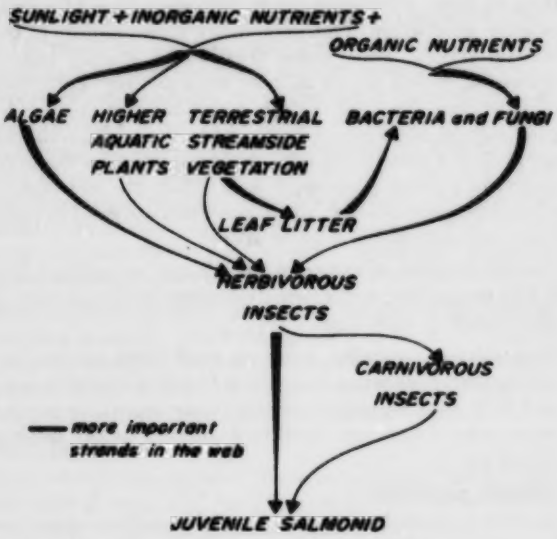


Figure 6.4 *Major strands in the food web leading to juvenile salmonids (Adapted from Mundie, 1974).*

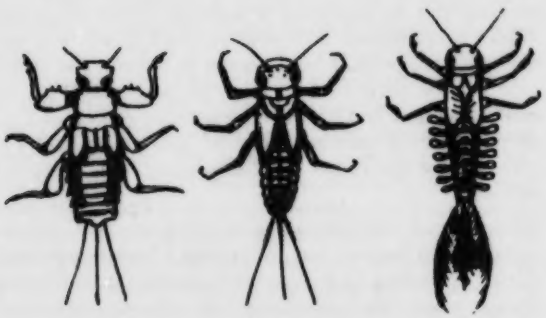
population will enter the *drift* and thus become available to juvenile salmonids (Fig. 6.6).

The relative importance of aquatic versus terrestrial insects in the diet of juvenile salmonids depends largely on stream size and flow level. Though aquatic insects are the most common food, terrestrial insects are important in relatively small streams with extensive overhanging cover, and also in late summer when stream flow is low, perhaps even intermittent between pools. In smaller streams most of the energy derived by aquatic insects comes from organic matter contributed from the surrounding watershed. In larger streams, however, algal production in riffle areas assumes greater importance as a food for the insects.

Factors Limiting Salmonid Production

Anadromous salmonids utilize a wide variety of streams. Though each species has its own particular requirements, some generalizations can be made with respect to habitat features. Successful spawning and embryonic development from the egg to fry stages requires:

(1) the absence of barriers to upstream movement of adults;
(2) spawning areas, usually in riffles, with a substrate of stable and permeable gravel, relatively free of sediment;
(3) a pool: riffle ratio that provides spawning area and escape cover in close proximity;
(4) a sustained flow of well-oxygenated water through the spawning gravel.



PLECOPTERA (STONEFLY) NYMPHS

PTERONARCIDAE FAMILY
(Pteronarcys): LENGTH TO 50MM; GRAZERS; INHABIT AQUATIC VEGETATION & LEAF MASSES; SOMETIMES FOUND UNDER ROCKS IN QUIET RIFFLES.

PERLODIDAE FAMILY
(Isogenus): LENGTH TO 25MM; PREDATORS; FOUND UNDER ROCKS IN QUIET RIFFLES OR FREE-RANGING ON THE BOTTOM IN QUIET WATERS.

EPHEMEROPTERA (MAYFLY) NYMPHS

EPHEMERELLIDAE FAMILY
(Ephemerella doddsi): 8-18MM LONG; GRAZERS; INHABIT SILTED AREAS; LEAF MASSES & AQUATIC VEGETATION; SOMETIMES FOUND UNDER ROCKS IN QUIET RIFFLES. ONE SPECIES (E. doddsi) ADAPTED TO CLING TO UNDER SURFACES OF ROCKS IN FAST WATER.

HEPTAGENIIDAE FAMILY
(Rhithrogena): 8-18MM LONG; GRAZERS; GILL STRUCTURE IS LIMPET LIKE, ENABLING NYMPHS TO CLING TO UNDERSURFACES OF ROCKS IN FAST WATER.

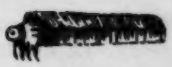
BAETIDAE FAMILY
(Baetis): 4-15MM LONG; PRIMARILY GRAZERS; STREAMLINED NYMPHS, MANY WITH HEAVILY-FRINGED CAUDAL APPENDAGES; EITHER FREE-RANGING IN BACKWATERS OR FOUND CLINGING TO THE UNDERSURFACES OF ROCKS IN RIFFLES.

TRICHOPTERA (CADDISFLY) LARVAE

HYDROPSYCHIDAE FAMILY
(Hydropsyche): LENGTH TO 15MM; NET WEAVERS; FOUND IN RIFFLES TENDING THEIR FUNNEL-SHAPED NETS IN WHICH FOOD IS COLLECTED.

LIMNEPHILIDAE FAMILY:
(Limnephilus): BUILD CASES TO 50MM LONG; VEGETARIANS; FOUND FREE-RANGING ON BOTTOM; CASES ARE CONSTRUCTED OF STONE, SAND, TWIGS, LEAF FRAGMENTS--ALMOST ANY SUITABLE MATERIAL COMMON TO THE PARTICULAR HABITAT IN WHICH THEY DWELL.

BRACHYCENTRIDAE FAMILY
(Brachycentrus): BUILD CHARACTERISTIC CASES OF TWIGS, SQUARE IN CROSS-SECTION; CASE TO 12MM LONG; VEGETARIANS; FOUND UNDER ROCKS IN RIFFLES.



CHIRONOMIDAE (MIDGE) LARVAE & PUPAE

(Chironomus): LARVA TO 15MM GRAZERS; BUILD TUBES FROM SECRETED MATERIAL IN SILTED OR MUDDY BOTTOMS.

(Chironomus): PUPA TO 20MM; RISES FROM BOTTOM TO EMERGE AT SURFACE; ADULT IS MOSQUITO-LIKE; MALES HAVE NOTICEABLY-PLUMED ANTENNAE.

Figure 6.5 *Examples of aquatic insect larvae from the principal orders important in the diet of stream-rearing juvenile salmonids. The species in each group are described in order from left to right.*

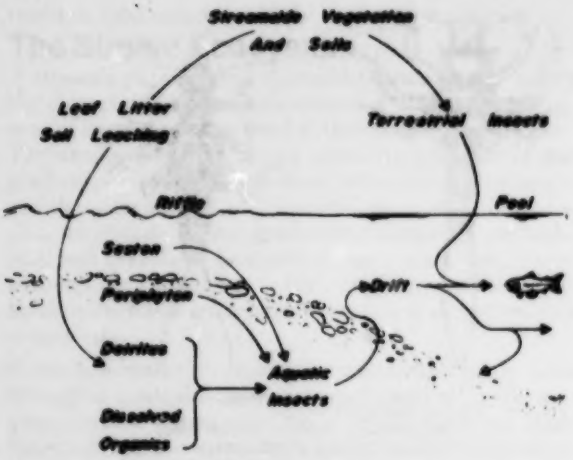


***Figure 6.6** Sources of insect drift food for juvenile salmonids in streams. Seston includes suspended particulate matter (living and non-living). Periphyton refers to aquatic plants living on or attached to the stream bottom (Adapted from Mundie, 1974).*

Productive juvenile rearing habitat usually possesses the following characteristics:

(1) low to moderate stream gradient and water velocities;
(2) a diversity of pool and riffle habitat;
(3) a variety of substrate types, such as gravel, cobble and boulders to provide habitat for both juvenile fish and fish food organisms;
(4) undercut banks, natural stable debris and overhanging vegetation to provide habitat for both juvenile fish and leaf litter for aquatic insect production; and
(5) sufficient nutrients to promote production of algae and decomposition of organic material.

A relatively stable flow regime and an absence of pollutants, including suspended sediments, are also important prerequisites for a highly productive salmonid stream.

These habitat features establish the *carrying capacity* of the stream for salmonids. Populations which temporarily exceed these environmental limits are brought back into balance by compensating increases in natural mortality. For pink and chum salmon, which have no freshwater rearing requirement, available spawning area is generally the limiting factor. When there are excessive numbers on the spawning grounds, eggs deposited by the earlier spawning members of the population may be dislodged from the gravel and destroyed by waves of later-spawning salmon. For the stream rearing species, such as coho salmon and steelhead trout, the amount and quality of juvenile nursery area place limits on production of smolt migrants. Juveniles surplus to the rearing or carrying capacity of the stream are forced to move into less suitable areas where access to food and shelter from predation may be restricted.

Within these limits imposed by available habitat, salmonid populations fluctuate considerably due to environmental factors which vary from year to year. Stream flow conditions for example, cause wide variations in freshwater survival and subsequent adult returns. In coastal streams, extreme floods may scour spawning beds, thus destroying eggs and alevins. Low stream flows during the winter incubation period may cause exposure and freezing of spawning beds, and in spring low flows may strand fry ready to emerge from the gravel. Low summer flows and extreme winter freshets can reduce rearing area, and consequently the production of coho and steelhead smolts.

The effect of stream flow conditions on egg-to-fry survival of salmon has been well documented. In coastal streams, where large fluctuations in flow are common, egg-to-fry survival can be expected to average about 10 percent. Under a controlled flow regime, with flows in a much narrower range than would occur in nature, the survival rate can be increased to over 25 percent. With both controlled flow and improved spawning gravel, in a completely artificial spawning channel, salmon egg-to-fry survival can be increased still further to levels of 40 to 80 percent.

Stream temperatures may also affect survival, although usually in an indirect way Abnormally high temperatures during spawning migration have resulted in outbreaks of disease among mature salmon, with consequent mortality prior to spawning. Higher than normal temperatures during winter incubation will increase the rate of development from egg to fry, necessitating premature emergence of fry from the gravel before the normal spring increase in food supply.

The foregoing discussion touches on the more important factors affecting freshwater survival and production of anadromous salmonids. Though it is the physical characteristics of a stream which mainly determine its capacity to produce salmonids, the strength of each year class is governed by the combined effect of these physical constraints and the many environmental variables which influence survival in both the freshwater and marine phases.

Examples of natural survival rates are presented in Table 1 for five anadromous species. It is interesting to note the inverse relationship between freshwater and marine survivals. Species such as steelhead trout, with a relatively long rearing period and consequent low survival in freshwater, enjoy a relatively high marine survival rate, no doubt due to the large size of the smolts.

Habitat Impairment

Many of man's activities have a detrimental impact, either directly or indirectly, on salmonid streams. Land uses for logging, mining, agriculture, roads, housing and industrial development have reduced the productive capability of many streams. The use of water for hydro-electric generation and for domestic and industrial water supplies has also had its effect. The following paragraphs briefly describe the major sources of habitat degradation.

Table 1. *Freshwater and marine survival rates of five anadromous salmonid species, as indicated by data from the Big Qualicum and Keogh rivers on Vancouver Island. Observed ranges are shown in brackets.*

Species	*Percent Freshwater Survival (egg to seaward migrant)*	*Percent Marine Survival*[1] *(migrant to adult)*
Chum	11 (5-17)	0.7 (0.1-1.4)
Chinook	4 (0.1-17)	2 (0.2-7)
Coho	2 (0.4-5)	11 (5-16)
Steelhead	0.4	15
Dolly Varden	0.4	25

[1]*Survival rate does not include marine catch of chinook and coho salmon.*

Large-scale clearing of vegetation in a watershed, whether for commercial timber harvest, housing or other development (Fig. 6.7) tends to increase both the total runoff and the rate of runoff from precipitation, particularly at the higher elevations in a watershed. As a result, the peaks of stream flow increase markedly and the stream channel, especially the banks and spawning area, becomes less stable. Soil erosion from such activities as road construction, road washouts, landslides, and land preparation for housing leads to sediment deposition in streams (Fig. 13.2). Sediment can have serious effects on salmonid habitat, by clogging spawning gravel, smothering aquatic insects on the stream bottom, and filling in pools which have served as habitat for juvenile salmonids.

***Figure 6.7** A small watershed subject to clearcut forest harvesting. Increases in peak stream flow, temperature, and sedimentation could be expected. Considerable bank erosion and an absence of stream bank cover for juvenile salmonids are evident in this photograph.*

Logging debris can also cause obstructions to fish migration, as well as serious diversions of stream channels (Fig. 6.8).

Near centres of population and in farming areas, streams are frequently channelized and dyked to prevent flooding (Fig. 6.9). This practice results in a straighter, more confined stream channel, with higher gradient and water velocities than the original channel. Under these altered conditions, there is less diversity of habitat and cover for rearing salmonids, and the pools suitable for adult salmonids are destroyed. The remaining substrate material is usually too coarse for spawning.

Chemical pollution from industries and urban development also degrades stream environments in certain areas. Leaching of toxic pollutants from garbage disposal and landfill areas, pesticides and herbicides are among the most common sources of stream pollution.

Water management projects designed to generate electricity or to provide water for domestic and industrial use, have also had major impacts on salmonid populations. The dams constructed have, in some cases, been either barriers to upstream migration or have caused mortality to

***Figure 6.8** Logging debris in a small stream – a potential obstruction to both fish migration and stream flow, often resulting in bank erosion and cutting of new stream channels.*

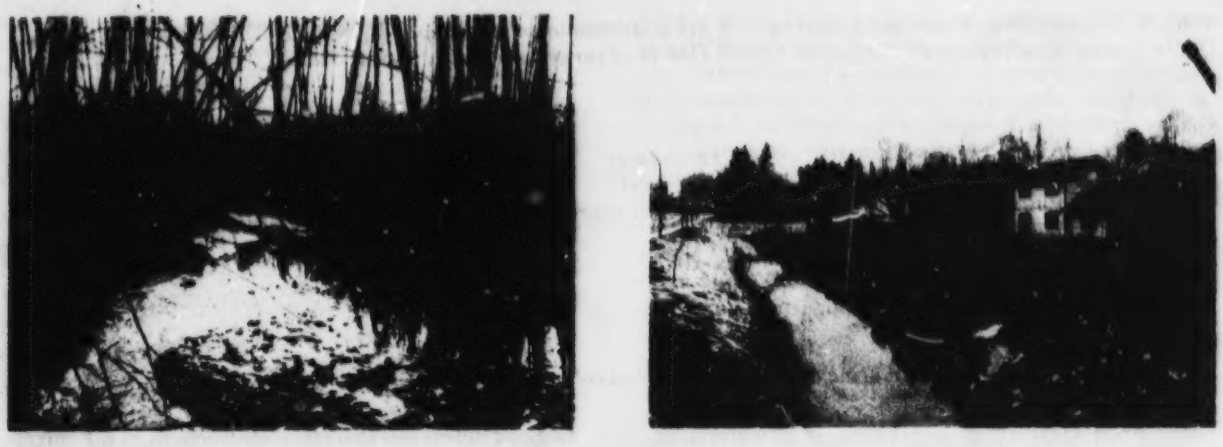


Figure 6.9 *Two faces of an urban stream supporting coho salmon and cutthroat trout – a section of the natural stream (**left**) with pool and riffle sequence, bank cover and shade, and a channelized section (**right**) beside a housing development several hundred metres downstream.*

smolts on their seaward migration. Diversions of headwater tributaries have also left too little flow in the original stream to provide adequate spawning and rearing area.

Another widespread problem for salmonid populations has been the use of culverts at road crossings. When properly designed and installed, culverts can pass both water and fish effectively. Far too frequently, however, culvert installations present a barrier to upstream migration because they are either too small to adequately handle the flow, or they are installed so that the velocities or entrance conditions are unsuitable.

Most species of salmonids rear in stream estuaries and tidal reaches for some period of time enroute to saltwater. The tidal channels, sloughs and backwaters which are so important during this phase of life are also extremely vulnerable to encroachment and alteration for ports and other forms of development. These commonly involve landfills and causeways. In some instances, log storage and dumping have also affected estuarial rearing areas.

Under present circumstances, with an increased awareness of environmental problems and stricter legislation, some of the examples of habitat degradation noted above would not occur. Nevertheless, a vigorous effort of recording and reporting actual or potential losses of salmonid habitat is required if the resource is to be maintained and enhanced.

7. PLANNING THE PROJECT

To be effective, stream enhancement projects must be carefully selected and planned. Each stream must be treated as an individual case, and certain streams will lend themselves to improvement more than others. Some streams may have no potential for increasing their capacity to produce salmonids unless the more sophisticated artificial techniques are utilized. Such techniques are beyond the scope of this guide.

As a first step, habitat limitations must be correctly diagnosed. This is best carried out with input from a fishery biologist or technician with training in this field. Once the diagnosis has been made, it then remains to select the enhancement technique or approach most appropriate to the particular situation.

Seasonal timing of stream enhancement projects is also important. Work within or alongside a stream should generally be undertaken during the summer low-flow period, to minimize damage to banks and reduce the spread of silt in the stream. Work in streams during the incubation period, when eggs or alevins would still be in the gravel, must be avoided. The period available for work may therefore be quite shor In some streams, salmon spawning starts in September and trout fry are still emerging from the gravel in early July, leaving a two-month period when work can be safely conducted within the stream.

In choosing enhancement techniques, one should keep in mind the desirability of preserving and restoring the natural character of the stream.

Assessing the Potential for Enhancement

The assessment for enhancement potential must determine the status of the salmonid populations, and what features of the stream environment may be limiting their survival and production. As a starting point, local officers of the government resource management agencies should be contacted to establish what information is available on the stream and its populations.

Information sources would include the local and district offices of the federal Fisheries Service and the regional fisheries biologist of the provincial Fish and Wildlife Branch. Factors to consider in this assessment are briefly outlined below, and a checklist is included in Appendix C.

Salmonid Stocks and Habitat

The present status and historical abundance of salmonid populations should be determined, as well as how much of the stream system they use and their principal spawning areas. This information may be available in the files or reports of the fishery agencies. If necessary, data on fish distribution and spawning areas can be obtained by field surveys at the proper times. With certain species, such as steelhead and cutthroat trout, statistics on sport catch may be the only quantitative data available.

The length of the main stream and all tributaries with fish production potential should be determined from available reports or measurements from topographic maps. The existence and approximate area of lakes should also be noted, as these may offer potential for flow control, or may be providing considerable natural stabilization of the flow regime.

If no physical surveys have been conducted by government agencies, the stream and its tributaries should be surveyed on foot or by boat to obtain the following information: the amount and distribution of potential spawning and nursery areas for the species of interest; location of potential adult holding pools; obstructions to upstream migration of adults; and salmonid production potential upstream of each obstruction. Surveys should be conducted when the water is clear and flows are at a low to medium level. The characteristics of salmonid rearing and spawning habitat are described in Section 11.

Information concerning salmonid stocks and stream conditions must be compiled and analyzed to determine the factors which probably limit salmonid production. The analysis must take into account the species of interest and its particular habitat requirements. For species with a freshwater rearing requirement, such as coho salmon and steelhead trout, the amount and quality of rearing area will generally be the limiting factor. For pink and chum salmon, on the other hand, spawning area will limit production. Once the limiting factors have been identified, any plans to improve existing habitat must also consider the behaviour of the species in question. For example, as chum salmon generally do not spawn far from saltwater, spawning area improvement for this species should be confined to the lower reaches of a stream, within the normal distribution of spawners. Otherwise, improved reaches of stream are not likely to be utilized to any extent.

Though a stream enhancement project may be designed to affect one species of salmonid, the project's impact on other salmonid species must also be considered. Measures to improve spawning habitat, for example, could cause a loss of rearing habitat if the importance of pools, undercut banks, logs, boulders and other cover features is not taken into consideration.

Wherever possible, the assistance of a fishery management specialist should be sought in developing plans and proposals for stream enhancement projects. Professional input should come early in the planning stage, before any intensive effort is expended on gathering background information.

Water and Land Use

The history of land and water use activities in the watershed and potential future development should all be taken into account in planning a project. Historical information may help to explain the present status of the fish populations. Possible future land use or water use, which could affect the stream adversely, should be taken into account in coming to a decision on feasibility and location of the project.

The fishery management agencies may be able to provide information on the various water and land use activities

which may be affecting the stream. Other direct sources of information are listed below.

Water Rights Branch

This provincial agency issues licences for activities to be conducted within the stream, such as: modifications to the channel, flood control structures, and construction and operation of dams for water storage, diversion, and abstraction from the stream. Information concerning water licences and their conditions may be obtained from the office of the Regional Engineer.

Pollution Control Branch

Information concerning permits to discharge effluent into a stream, and the conditions of those permits, may be obtained from the regional office of this provincial agency.

Land Registry

Any questions of land ownership and the status of land in the watershed should be directed to the appropriate local land registry office.

Forest Service

Information on forest harvesting activity in the watershed, plans for the future, and on access to a forested area may be obtained from the district office of the provincial Ministry of Forests.

Municipal and Regional Government

Municipal or regional government offices can provide information concerning land use plans and developments slated for the watershed, particularly in the vicinity of population centres.

Fishery Management

The appropriate managment agency must be consulted to determine how the proposed project fits in with its plans for management or enhancement of the stock concerned. The agency will also be able to advise on where the stocks are fished, and whether or not the fisheries are intense enough to affect the feasibility of the project by seriously reducing rates of adult return to the stream.

Legal Considerations

There are several pieces of legislation which may apply directly or indirectly to a stream enhancement project. The principal legislation is contained in the Water Act of British Columbia and Fisheries Act of Canada. The Water Act pertains to any activities which could either affect stream flow, ie. through storage or diversion of water, or alter the stream and its channel. An approval or licence must be obtained from the Comptroller of Water Rights before any work is carried out within a stream. The Fisheries Act contains provisions to prevent the harmful alteration of fish habitat, obstruction of fish, and the depositing of substances deleterious to fish. It also regulates activities involving the capture, holding, retention, transfer and breeding of fish. This Act is administered by both the federal Department of Fisheries and Oceans and the provincial Fish and Wildlife Branch. In British Columbia, the federal agency is responsible for the management and protection of marine fishes and Pacific salmon. Responsibility for management and protection of all freshwater fish, and anadromous species other than salmon, ie. steelhead and cutthroat trout and Dolly Varden char, has been delegated to the provincial agency.

Some municipalities have also enacted bylaws under the Municipal Act, to restrict alterations to local streams and watercourses in much the same manner as the provincial Water Act. These bylaws may require that approval to alter or improve a stream be obtained from the municipality's engineering department or other designated authority.

Where stream enhancement activities involve the use of provincial Crown Land, the initiator of a project should be aware that use of such land may be administered by one of three provincial agencies, depending on its classification or designation. Provincial forests, including land under Timber, Pulp or Tree Farm Licence, are administered by the Ministry of Forests. Provincial parks are administrated by the Parks Branch. All other Crown lands come under the jurisdiction of the Lands Management Branch.

In the case of private land, permission of the owner is required to obtain *right of trespass*.

If a project involves changes to the water quality of a stream, eg. the effluent from a fish culture site or the addition of fish toxicants to eliminate predator fishes, the provincial Pollution Control and Pesticide Control acts would apply. Information on permits and approvals may be obtained from the Regional Director of the Ministry of Environment. In addition, the provincial Heritage Conservation Act could apply in the unlikely situation where a provincial Heritage Site may be affected.

Even when all necessary government approvals and permits have been obtained, the project's initiator remains legally responsible for any resulting detrimental impact on private property, either upstream or downstream of the proposed project. Under certain circumstances structures within or along the stream may also constitute a hazard to the public. The individuals responsible for the project may be liable for injuries or damages, to the public or adjacent property owners, which can be attributed to the project.

Project Approval

Any group or individual planning to undertake a stream enhancement project will require approval from government agencies. The approval of the federal Department of Fisheries and Oceans and the provincial Fish and Wildlife Branch will be required for all proposed projects. In many cases, approval of the provincial Water Rights Branch will also be needed.

To assist in the review and approval of proposals from the public to undertake salmonid enhancement work, the Salmonid Enhancement Program has established Community Advisors in a number of district fisheries offices to provide technical assistance and to act at the point of contact with the public. A group proposing a stream enhancement project should first contact the Community Advisor or the local Fishery or Conservaton Officer. Once the contact has been established, the Community Advisor will assist the group in submitting their proposal. The proposal should clearly state the nature and location of the

project, expected costs, and benefits. Project application forms are available from the local offices of the federal Fisheries Service and the provincial Fish and Wildlife Branch.

On completion of the applicaton the Community Advisor will guide it through the review process (Fig. 7.1). The proposal will first be reviewed by both federal and provincial fisheries managers for its technical viability and compatibility with other projects or activities in the same area. Next, the proposal will be reviewed by Salmonid Enhancement Program managers to ensure that it is consistent with the overall plan. If the project does not meet with approval at any stage, the Community Advisor will assist the sponsoring group in redrafting the application.

Once a project has been approved, the Community Advisor will continue to provide advice and assistance in implementing the project, and will keep other fisheries agency personnel informed as the project proceeds.

The approval process can be time consuming. Considering that there may be seasonal constraints on the work planned, it is wise to submit plans for a project to the appropriate agencies during the winter or early spring, if possible. For more sophisticated projects, it may be advisable to develop and submit a proposal six months or more in advance. This applies to projects being carried out by either the public or fisheries agency staff.

APPLICANT
COMMUNITY ADVISOR
FEDERAL AND PROVINCIAL FISHERIES STAFF AT LOCAL AND REGIONAL OFFICES
FEDERAL AND PROVINCIAL FISHERIES GEOGRAPHIC WORKING GROUP

Figure 7.1 *Lines of communication in reviewing and approving salmonid enhancement projects initiated by the public.*

8. ENHANCEMENT TECHNIQUES — INTRODUCTION

The fishery resource agencies in British Columbia have considerable experience in the large-scale approaches to salmonid enhancement, such as hatcheries, artificial spawning channels, flow control, and fishways (Fig. 8.1). Smaller projects such as removing log jams and other obstructions to migration, have also been carried out for many years. On the other hand, experience with improving physical habitat within the stream is quite limited in this region. Many of the stream improvement methods used successfully in eastern North America are difficult to apply on the Pacific coast, because our streams have a greater range in flow and higher gradient than eastern streams. The results of stream improvement projects may therefore be less predictable, and useful life of structures and improvements within the stream will tend to be lower than experienced in central and eastern North America. These disadvantages are offset, however, by the high production potential of Pacific Coast anadromous salmonids, owing to the diversity of species and the substantial growth they attain in the sea.

There are many approaches to stream enhancement. The appropriate choice depends on the species, the status of the fish stock involved, and the physical characteristics of the stream. First consideration should be given to measures which protect or maintain the natural environment. *As some of the techniques described here have been applied in British Columbia to only a limited extent, caution must be exercised in their application.* Projects should also be assessed to provide a basis for guiding future efforts, and should often be phased over two or more years, so that the experience gained from the initial work can be applied in the later stages.

***Figure 8.1** A large artificial spawning channel for sockeye salmon at Fulton River on Babine Lake, northern British Columbia. The channel is 4.8 km long and accommodates 130,000 spawners.*

9. STREAMSIDE AND WATERSHED IMPROVEMENTS

Land and stream are linked directly by water moving in the hydrologic cycle. Organic and inorganic materials, which support the base of the food chain in streams, flow continuously from the land. The quality of water and availability of food for juvenile salmonids are therefore determined largely by the character of soils and vegetation in the surrounding watershed. Accordingly, man's activities in watersheds can have pronounced effects on the quality of the stream environment. Road building and the clearing of land for various forms of development inevitably cause soil erosion and subsequent deposition of sediment in the stream substrate. Clearing of forest cover also increases runoff from the watershed, and produces higher peak flows. These changes in flow regime tend to reduce streambed stability, causing spawning areas to shift, streambanks to erode, and pools to fill in.

Streamside Vegetation

The vegetation along the stream influences its character and its suitability for rearing salmonids. The degree of shading by the surrounding forest canopy has a marked influence on stream temperature. The root systems of streamside shrubs and trees help to maintain the integrity of the stream bank, thereby resisting erosion and assisting in the formation of the pools and undercut banks favoured by juvenile salmonids.

Streamside vegetation also affects the food web leading to salmonids. By influencing the amount of light reaching the stream, trees affect production of aquatic algae and, consequently, the production of aquatic insects. The leaves and needles which fall into the stream also provide organic material, which contributes to aquatic insect production.

Though the evidence is limited at this point, it appears that because of their relatively high rate of decomposition and their high nitrogen content, deciduous trees and shrubs may be more important contributors to the food web than coniferous trees. The principal deciduous species found along British Columbia streams are alders, willows, and cottonwood.

A mixture of deciduous and coniferous trees along the stream is desirable. Whereas conifers may be needed to give protection from freezing winds in winter, willows can provide excellent overhanging cover and a source of terrestrial insects for juvenile salmonids. However, willows can sometimes be a problem where they become established in the streambed and encroach on the channel.

It has been suggested that selective cutting and removal of streamside trees could benefit juvenile salmonids. This would allow more light to reach the stream, thus increasing algal production and promoting regrowth of deciduous vegetation. A consequent rise in water temperature would increase the growth rates of juvenile salmonids, perhaps reducing their age at seaward migration and increasing the size of smolts, thus enhancing their prospects for survival. To date, there has been no experimentation to determine the actual feasibility of this concept. For many streams, such as those below lakes or in the warm, interior region, the likelihood of excessive temperature increases would be a constraint.

Under present forest management policy in British Columbia, forest harvesting plans must include measures to protect streams and the adjacent land area. Specific plans must be developed by the company concerned for harvesting the timber along each stream. Where excessive blowdown of trees is not likely to occur and where recreational use is high or slopes unstable, strips of trees are left along the stream. Along other reaches only the deciduous, non-commercial trees are left standing.

Obviously, there is considerable potential to influence the quality of the stream environment by manipulating streamside vegetation. Planting of willow cuttings is an established method of controlling bank erosion and providing cover for salmonids. However, selective removal of streamside trees must be considered a purely experimental approach that requires further research and evaluation before it could be recommended for general application.

Erosion and Sediment Control

Erosion and sediment transport are natural phenomena which can improve as well as degrade fish habitat. Eroding gravel banks provide a continuing source of gravel for the stream. High stream flows may shift gravel bars, cleanse spawning beds and form or deepen pools, all to the benefit of spawning and rearing salmonids. But the erosion of fine textured soils such as clays, silts and fine sand can reduce the quality of habitat. In streams flowing through this type of soil, the effects of stream enhancement work may be negated if erosion is not reduced or controlled.

Bank Erosion

The banks of some streams, particularly those with a high proportion of silt and clay fines must be stabilized, to prevent the erosion and deposition of this material on spawning beds or in pools used for rearing. In some cases, severe bank erosion has led to formation of a new stream channel, leaving once productive channels dry and barren. As the banks erode, trees and other vegetation fall into the stream and this in turn speeds up the erosion cycle. The resulting sedimentation and debris jams can render an entire section of stream unsuitable for salmonid production.

Eroding stream banks can be stabilized with gabions, quarry rock or log walls (Fig. 9.1). On some sites a small upstream wing deflector may be required in order to direct the main flow away from a large cutbank of silts or fine sands. This type of bank stabilization can also benefit rearing salmonids. Spaces between rocks and gabions and protrusions near the stream bottom will provide holding and rearing places for juvenile fish.

In areas above the high water level, planting of trees and

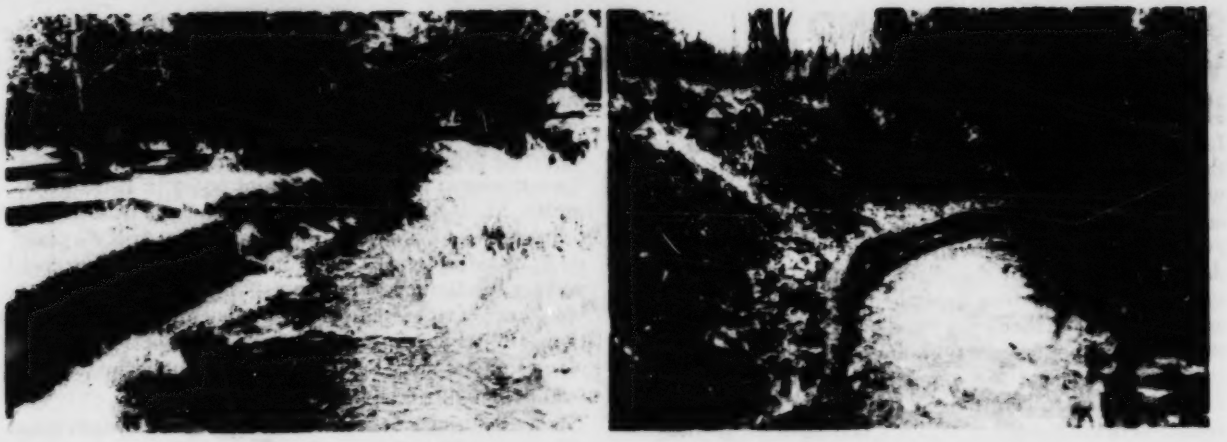


Figure 9.1 *Stream banks stabilized with rock filled gabions* **(left)** *and walls constructed with logs* ***(right)****. Upper areas of the embankment can be planted with trees or seeded with grass to minimize the amount of silt entering the stream.*

subsequent root development will reinforce the soil and prevent silt and fine debris from entering the stream. Where banks must be stabilized quickly, a mixture of organic fiber mulch, fertilizer and selected grasses can be used. In coastal climates the grass mixtures would generally consist of Alsike and White Clover, Perennial Rye and Reed Canary Grass, Timothy, Creeping Red Fescue, and Fall Rye. The various factors associated with the use of these grasses and legumes are:

**Alsike Clover*	A hardy legume, ideally suited for poor soils.
**White Dutch Clover*	One of the few legumes that stands up to regular cutting. Ideally suited for soils with high sand-gravel content.
Perennial Rye Grass	Has very rapid growth in spring and fall. Ideally suited for slope stabilization when applied during spring and fall.
Timothy	Ideal grass for wet areas.
Reed Canary Grass	Suited for applications where the area may be flooded for extended periods.
Creeping Red Fescue	Noted for its excellent root growth (binds soils together to resist erosion).
Fall Rye	Used as a nurse crop when grasses and legumes are planted in the fall.

**It should be noted that where legumes are not natural to the area, the seed must be mixed with a bacteria producing innoculant to promote the natural production of fertilizer for the plant.*

For other areas of the Province the requirements will differ. The provincial Ministry of Highways uses selected grasses and legumes to stabilize highway cuts and embankments throughout British Columbia. Because of their experience, Ministry personnel are an excellent source of information for any specific region or soil type.

The mixture of grasses and legumes is commonly applied by spray. Due to the fiber mulch content it is effective immediately. The fibers interlock with the soil to prevent formation of continuous rainwater paths which could flow together to create deep erosion gulleys. In two or three weeks the seeds germinate and the young grasses take root and further stabilize the soil. The recommended chemical fertilizer for coastal areas below an elevation of 1,200 m consists of 19% nitrogen, 19% phosphorus, and 19% potassium. It should be applied at a minimum rate of 55 kg per hectare (300 lb/acre).

In some of the more arid areas of British Columbia intensive cattle grazing can lead to stream bank erosion, through overbrowsing of the grasses and shrubs which help maintain bank integrity. In these cases, streamside fencing is often used to exclude cattle so that vegetation can re-establish.

Evaluation of streamside fencing projects has shown that they do assist in restoring bank cover and reducing erosion, and that juvenile salmonid production from adjacent stream areas increased 2- to 3-fold. The longterm benefits in terms of fish production more than offset the costs of fencing.

Upland Erosion

Highway construction, urban development, agricultural clearing and logging activity often increase storm water runoff. If the runoff is concentrated in one area a major washout will occur. The washout shown in Fig. 9.2 occurred on a major fish-producing river and resulted in large quantities of debris, silt, sand, and gravel entering the river system. If the storm water flows had been diverted away from the bank and the slope stabilized with vegetation, this massive washout would probably not have occurred. It has been shown in one watershed that revegetation of logging road cut and fill slopes through fine textured soils reduced sediment transport in adjacent streams by 50%.

Mining companies lessen the environmental impact of

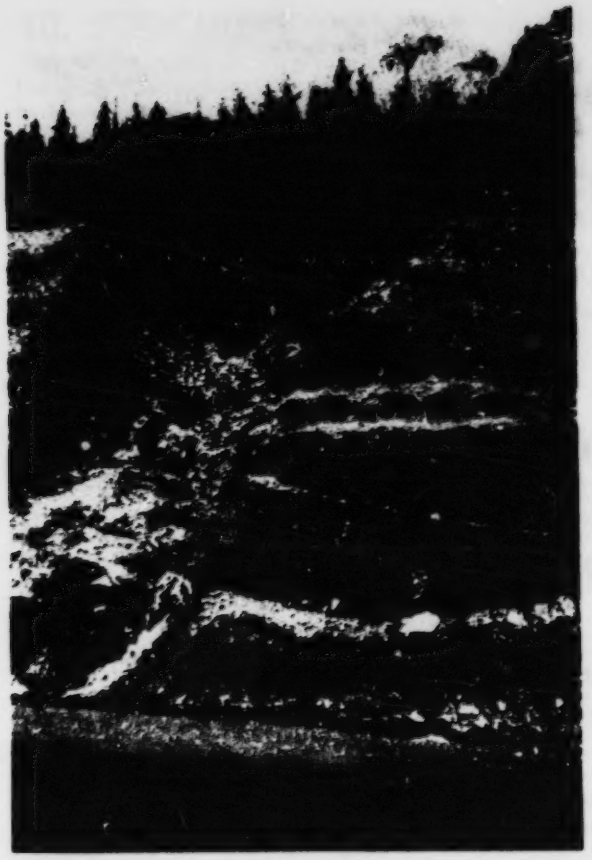


Figure 9.2 *A manmade concentration of stormwater runoff caused this embankment washout along a major fish-producing stream. Debris, sand and silt entered the watercourse and damaged spawning and rearing areas.*

open-pit mining operations by the use of two techniques to stabilize accumulations of overburden waste. To minimize the chance of fine debris or sediment entering the natural watercourses, the overburden waste is terraced and sloped as shown in Fig. 9.3. It is then hydroseeded with mulch, fertilizer and selected grasses suitable for the area. In cases where waste piles are excessively steep and immediate results are desired, the slopes can be covered with a woven jute mesh prior to seed application.

Where stormwater is collected within the mining operation and cannot be diverted around the mine, large settling ponds are often constructed to settle out the suspended solids from water entering the natural water courses. Major haul roads are constructed with perimeter embankmeets on each side of the road to prevent mine waste and fines from overflowing into the streams. At selected locations along the road, the storm water is diverted into large settling basins before being discharged to the stream.

Figure 9.3 *Large piles of overburden wastes from both active and abandoned mining operations can be terraced and seeded with select grasses to prevent silt and fines from entering nearby watercourses.*

Abandoned exploration and logging roads will gradually deteriorate. Water will channelize within the road and create erosion. Culverts will plug and wash out, causing silt and debris to enter streams. In many of these cases, it is beneficial to eliminate the abandoned road and restore the terrain to its natural slope. Revegetation of the disturbed areas can then be carried out by hand or by hydroseeding. Fig. 9.4 shows the approach recommended by the Ministry of Mines and Petroleum Resources for restoring areas traversed by abandoned exploration roads.

An abandoned logging or mining road is sometimes maintained to provide access for fire fighting or recreational uses such as hunting and fishing. A simple technique for preventing excessive erosion of the road bed is to construct shallow swales or depressions, timber sills or rock filled channels to divert runoff across the road at frequent intervals. These easily constructed devices provide considerable benefit relative to the effort involved.

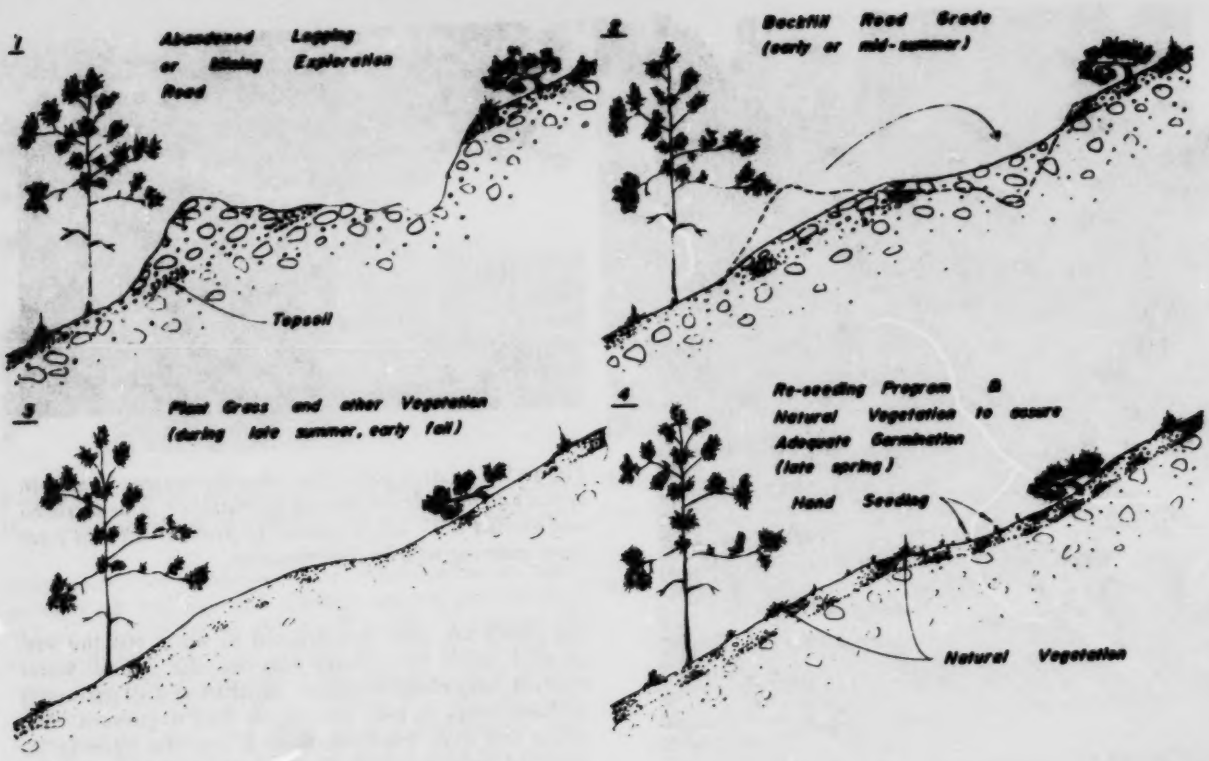


Figure 9.4 *Four recommended steps for reclaiming an abandoned logging or mining exploraton road. This approach can also be he applied to highly erodible cut and fill slopes of road systems.*

10. FISH SCREENING

Water is commonly diverted from streams and lakes for industrial plants, domestic water supplies, irrigation or hydroelectric generation. Such diversions of water are a potential source of injury and mortality to salmonids, particularly the juvenile stages. Several types of screen systems, varying in size, complexity and mode of operation, are used to prevent fish from entering water intakes or diversions. The following sections describe the various screen systems, emphasizing those approaches suited to smaller streams.

In accordance with Section 28 of the Fisheries Act *every water intake ditch, channel or canal in Canada constructed or adapted for conducting water from any Canadian fisheries waters for irrigating, manufacturing, power generation, domestic or other purposes, shall, if the Minister deems it necessary in the public interest, be provided at its entrance or intake with a fish guard or a screen, covering or netting, so fixed as to prevent the passage of fish from any Canadian fisheries waters into such water intake, ditch, channel or canal.*

To assist the public in complying with this legislation specifications for the design and construction of screening facilities have been prepared by the government agencies responsible for the fishery resource. The specifications appropriate for stationary screen installations on relatively small streams are summarized below:

Screen Material: The screen material shall be either aluminum, stainless steel, brass or bronze.

Screen Mesh Size: Clear openings of the screen (the space between strands) shall not exceed 0.10 in. (25 mm). The open screen area shall not be less than 50% of total screen area. The recommended screen is 8 strands per lineal inch, square-mesh wire cloth with .028 or .025 in. (0.71 or 0.63 mm) diameter wire.

Screen Area: A minimum unobstructed screen area of 10 ft^2 (0.93 m^2) shall be provided for each cubic foot per second (2050 litres/sec) entering the intake.* The required screen area shall be installed below minimum water level. (Screen area lost by framing shall not be included as part of the unobstructed screen area).

Screen Support: The screen shall be adequately supported with stiffeners or *back-up* material to prevent excessive sagging.

Screen Protection: The intake structure shall, where necessary, be equipped with a trash rack or similar device to prevent damage to the screen from floating debris, ice, etc.

Screen Accessibility: The screen shall be readily accessible for cleaning and inspection. (Screen panels or screen assemblies which cannot be removed for cleaning, inspection and repairs should be avoided).

Allowable Openings: The portion of the intake structure which is submerged at maximum water level shall be designed and assembled so that no openings exceed 0.10 in. (2.5 mm) in width.

*1 cubic foot per second (cfs) = 450 U.S. or 375 Imperial gal/min.

Design and Location: The design and location of the intake structure shall be such that a uniform flow distribution is maintained through the total screen area.

For water diversions of less than 1 cfs the intake structures and associated screening facilities must be designed in accordance with the foregoing specifications. Upon completion of the work, the entire facility must then be inspected by a fisheries agency representative before being put into operation.

For diversions of more than 1 cfs, detailed drawings of screen systems must be submitted to the fisheries agency for approval. These installations are then appraised on a site-specific basis. Since the technical requirements of these larger intake facilities are very complex, only the main design considerations and operating features will be discussed in this guide.

Large, industrial water users often employ vertical, travelling screens to separate debris and trash from water being diverted (Fig. 10.1). With design modifications such screen systems can prevent juvenile salmonids from entering the intake. The wetted area of screen is normally increased to reduce the velocity of water approaching the screen to less than 7.5 cm/sec. This is required to prevent impingement of fish on the screen. Finer mesh screen (2.5 mm openings) may also be used to exclude small

***Figure 10.1** Travelling vertical water screens for a large pumped water supply. The opening on the downstream side of the intake allows juvenile salmonids to readily escape from in front of the screens if they are weakened by sustained swimming.*

salmon or trout fry. Rubber lip and edge seals may be added, to close any openings between the walls of the intake and the travelling screen. However, the seals must be inspected frequently to ensure small fish, particularly fry, do not find openings to swim through.

One problem associated with this type of screen is that fish can be caught in the horizontal trash collectors on the front of each screen section (Fig. 10.2). This problem can be minimized by modifying the horizontal trash collectors so they slope down and away from the face of the screen. This design provides reasonable debris-lifting capability, while enabling salmonid juveniles to flip or wiggle back into the water with relative ease. Another important consideration in designing such a screen system is the provision of an *escape route* for juvenile fish which may become weakened from sustained swimming in front of the screen. This can be accomplished by providing a simple passage or vertical slot in the downstream wall of the intake, aligned with the vertical face of the travelling screen (Fig. 10.1).

***Figure 10.2** The horizontal trash collectors on vertical travelling screens can trap juvenile salmonids and lift them clear of the water. Sloping the trash collectors will help the fish escape.*

Another type of screening system which has been used on large water intakes is the fixed, vertical screen (Fig. 10.3). The intake is normally constructed on the outside bend of the river coincident with a natural pool and parallel to the direction of flow. Water enters the intake structure through a coarse trashrack which protects the inner screen gallery from large logs and debris. A number of perforated aluminum screens are located parallel to the trashrack approximately 1.5 m inside the intake structure. The screens form a smooth, vertical wall which is fish-tight.

At the downstream end of the screen gallery, gates are located to maintain a suitable depth of water in front of the screens and to bypass at least 50% of the flow downstream. This results in a continuous washing action across the face of the screens, which removes debris and keeps the screens clean. The remaining water passes through the screens, free of debris and fish. Such a facility also requires an inclined weir across the river bottom to concentrate low flows on the intake side of the river, and thus ensure sufficient depth of water to operate the screens.

The fixed-screen intake, used extensively by fisheries agencies for spawning and rearing channels, can be adapted for a large range of flows. The screens require some maintenance, especially when there is an exceptional debris load such as after a storm or high winds. The screens do not impinge or injure small salmonid fry.

Another type of fish screen, commonly used on irrigation canals, is the revolving-drum screen. Its principal of operation is relatively simple. Water flows through the upstream side of the drum screen which prevents fish from entering the channel. As the drum revolves, by either a paddle wheel system driven by the river current or an electric motor, the debris is removed on the downstream side by water passing through the screen. Fig. 10.4 shows a small motor-driven drum screen installed on an irrigation channel.

One of the main considerations in the design of a drum screen, as with any screen, is to ensure that a bypass channel or other avenue of escape is provided for fish that accumulate in front of the screen. Experience with drum screen installations has shown them to be costly and to require frequent maintenance of seals and mechanical parts.

A simple and less expensive alternative to the drum screen is the horizontal-vertical screen combination, which has been used and tested on irrigation projects in British Columbia. As shown in Fig. 10.5, this type of installation is installed in a bypass channel off the main stream. Water flows into the irrigation channel through the horizontal screened floor and vertical end-wall of the facility. Fish and debris are returned back to the main stream through a bypass consisting of a culvert discharging into a channel. Tests on the screening facility indicated only occasional cleaning is required after prolonged periods of operation.

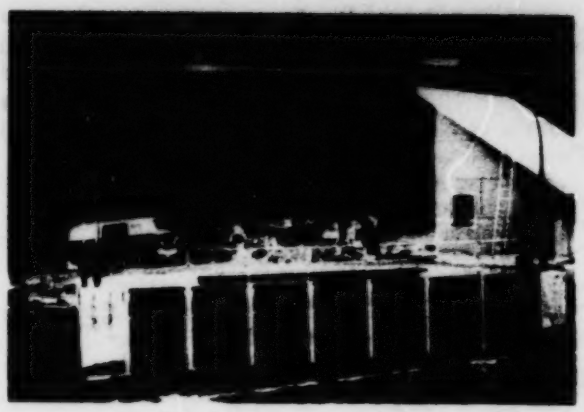


Figure 10.3 Fixed vertical screen intake. Water enters the screen gallery through the coarse trashrack and a portion of the flow is diverted to the water system through perforated aluminum screens. A sluice gate at the end of the intake regulates the amount of water which passes through and flushes across the face of the screen.

Figure 10.4 Small motor-driven drum screen installed on an irrigation water supply. To avoid fish being drawn into the rotating screen, a bypass channel must be provided for the small fish to readily escape.

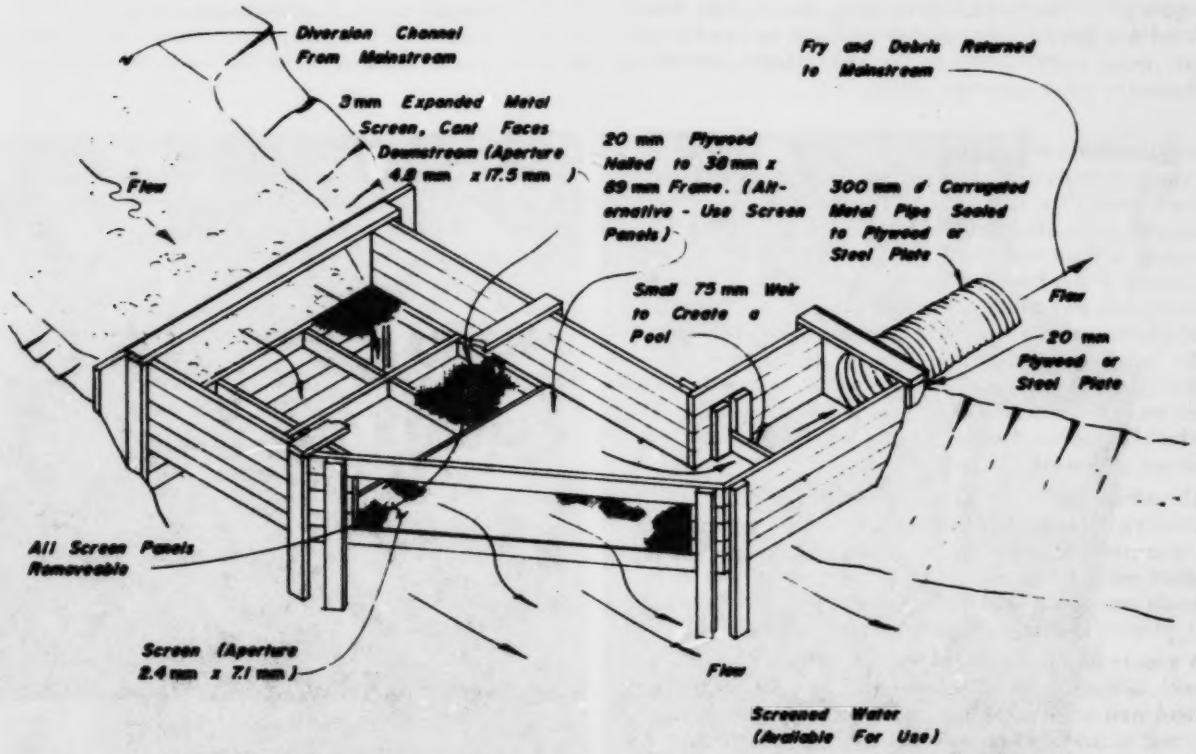

Diversion Channel From Mainstream
3mm Expanded Metal Screen, Cant Faces Downstream (Aperture 4.8 mm x 17.5 mm)
Flow
20 mm Plywood Nailed to 38 mm x 89 mm Frame. (Alternative - Use Screen Panels)
Fry and Debris Returned to Mainstream
300 mm ø Corrugated Metal Pipe Sealed to Plywood or Steel Plate
Small 75 mm Weir to Create a Pool
Flow
20 mm Plywood or Steel Plate
All Screen Panels Removeable
Screen (Aperture 2.4 mm x 7.1 mm)
Flow
Screened Water (Available For Use)

Figure 10.5 Horizontal-vertical screening facility located in a diversion channel off the main stream. Water flows through the horizontal and vertical sections of screen and is available for use in the irrigation channel or other water use facility downstream. Fish and debris are guided to the bypass culvert which discharges back to the main stream. (Adapted from P.A. Slaney, 1977).

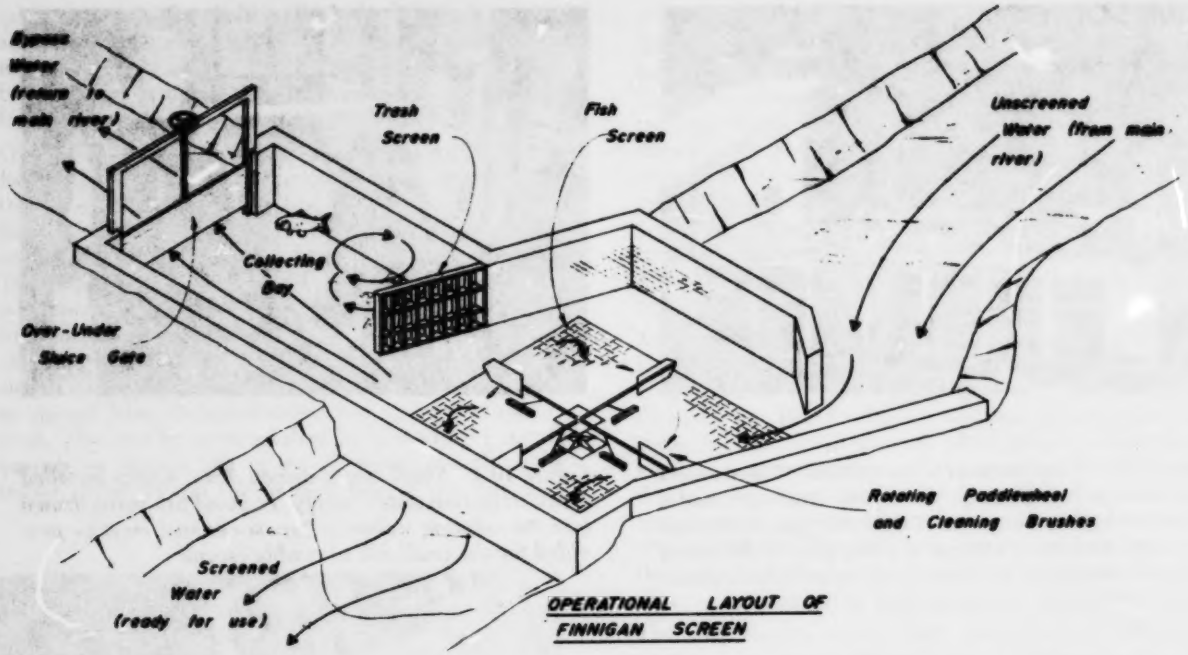


Figure 10.6 *Horizontal self cleaning water screen. Water is diverted from the main stream through a bypass channel. Water and fish pass over the horizontal screen and back into the main stream. Water levels are maintained by a simple gate device and/or stop logs. The water that passes through and below the screen is available for use in the irrigation channel or other water use facility.*

Another fish screening concept, also used primarily on irrigation projects, is the horizontal, self-cleaning *Finnigan Screen* (Figs. 10.6 and 10.7). This system consists of a smooth, perforated plate, installed so that the horizontal surface is flush with the bottom of the water diversion channel. Water flows down through the horizontal perforated plate and out into the irrigation channel through a false bottom under the screen. Surplus water flows across the horizontal screen and returns to the main river through a bypass channel. As the water flows across the screen, the current drives four horizontal paddles to which brushes are fastened. As the paddle arms turn, the screen is cleaned.

The advantages of the Finnigan Screen are that it is self cleaning, and that fish swimming across the screen with the current probably do not detect that water is being taken out through the screen. However, proper water levels are critical, and must be regulated with gates and stoplogs to maintain effective operation.

A simple intake screen, best suited to lakes and stable pools in streams, utilizes a customized section of stainless steel well screen. Well screens are fabricated from tapered stainless steel wire with longitudinal, tapered, stainless steel support rods. The wire rods are woven into a cylindrical section with a predetermined space between each wrap of wire. The space between each wrap of the wire, which varies for different screen installations, is known as the slot size. Well screens can be manufactured with a slot opening small enough to prevent fine sand from entering the water system. When sand and other particulate matter is not a problem, the slot size must be appropriate for the size and species of juvenile fish in the system.

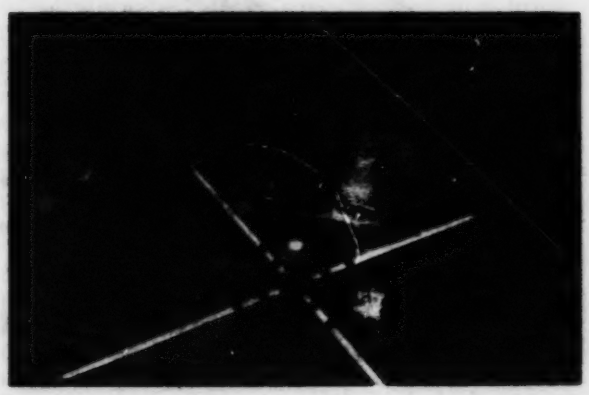


Figure 10.7 ***Finnigan*** *horizontal self cleaning screen, showing the paddle drives and cleaning brushes. Water flows out through the bottom of the screen to supply water free of fish and debris.*

Well screens have been used for all sizes of intakes ranging from 5 to 250,000 litres per minute. Summarized below are a few different types of intake systems incorporating well screens:

(1) Multiple well screens connected to a submerged pipeline on a lake bottom have been used to screen water for a municipal supply. The screens are normally positioned approximately 3 metres from the bottom of the lake to prevent silt and debris from entering the water system.

(2) A floating water intake can be fabricated utilizing two simple pontoons with a section of well screen supported between them. A flexible polyethylene pipeline can be connected from one end of the well screen to the shore. This type of intake can be used in either lakes or rivers, and is often ideal for supplying water to a fish egg incubation facility.

(3) A temporary intake may be constructed by connecting a flexible pipe to a well screen, which is raised above the bottom by simple support legs welded to each end of the screen (Fig. 10.8). This type of assembly may be installed in pools of streams, impoundments behind beaver dams, small lakes, or in other stable, clean water sources.

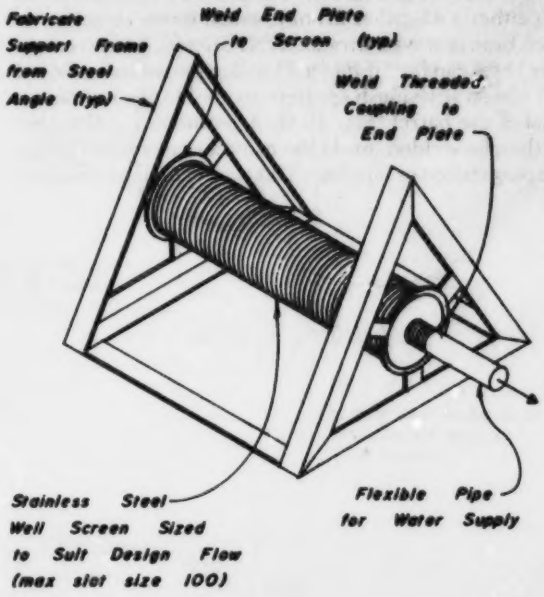

Fabricate Support Frame from Steel Angle (typ)
Weld End Plate to Screen (typ)
Weld Threaded Coupling to End Plate
Stainless Steel Well Screen Sized to Suit Design Flow (max slot size 100)
Flexible Pipe for Water Supply

Figure 10.8 Small prefabricated intake utilizing stainless steel well screen. The intake may be installed in lakes, stable river pools and beaver impoundments.

Figure 10.9 A simple screened intake can be made from a drum or welded rectangular frame covered with woven wire mesh. This intake can be used in a stream or lake, supported below the water surface from floats.

A small, inexpensive screened intake may be constructed with either a 45-gallon drum or wood frame structure to which bronze woven wire mesh is fastened. Large rectangular holes can be cut into a 45-gallon barrel and covered with woven wire mesh securely riveted to the remaining metal of the barrel (Fig. 10.9). A perforated outlet pipe can then be welded inside the drum to carry water to the pumping station or pipeline. This type of intake is ideal for suspending from a float system set in a lake or stream (Fig 10.10).

When employing this intake system on a water supply for fish egg incubation or rearing, metals toxic to fish such as zinc, copper, and their associated alloys must be avoided. Fiberglass and epoxy coatings can be used to extend the life of metals which corrode or to mimimize the effects of toxic materials.

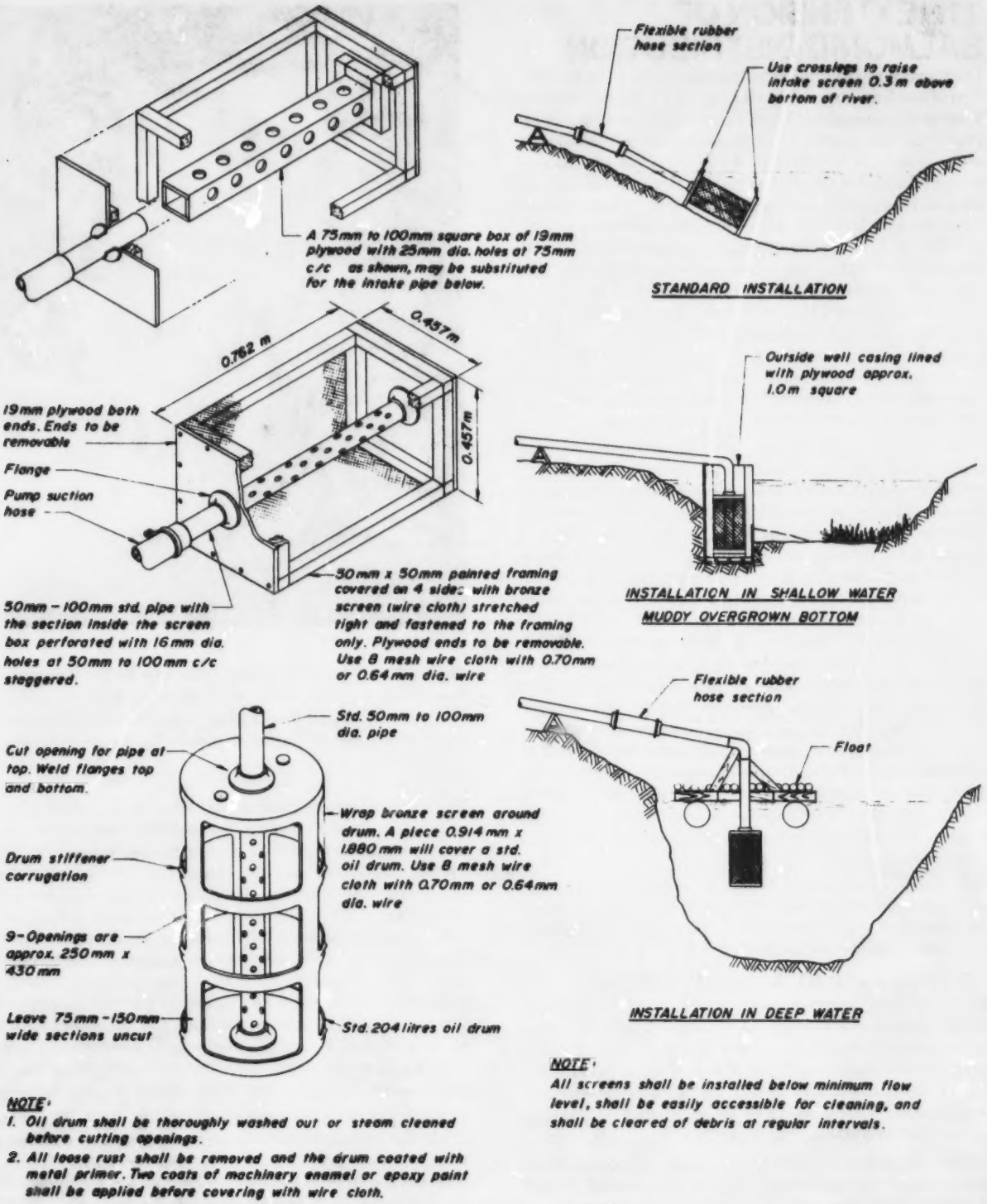

A 75mm to 100mm square box of 19mm plywood with 25mm dia. holes at 75mm c/c as shown, may be substituted for the intake pipe below.
Flexible rubber hose section
Use crossleg to raise intake screen 0.3 m above bottom of river.
STANDARD INSTALLATION
0.762 m
0.457m
0.457m
19mm plywood both ends. Ends to be removable
Flange
Pump suction hose
50mm - 100mm std. pipe with the section inside the screen box perforated with 16 mm dia. holes at 50mm to 100mm c/c staggered.
50mm x 50mm painted framing covered on 4 sides with bronze screen (wire cloth) stretched tight and fastened to the framing only. Plywood ends to be removable. Use 8 mesh wire cloth with 0.70mm or 0.64mm dia. wire
Outside well casing lined with plywood approx. 1.0m square
INSTALLATION IN SHALLOW WATER
MUDDY OVERGROWN BOTTOM
Std. 50mm to 100mm dia. pipe
Cut opening for pipe at top. Weld flanges top and bottom.
Wrap bronze screen around drum. A piece 0.914 mm x 1.880 mm will cover a std. oil drum. Use 8 mesh wire cloth with 0.70mm or 0.64mm dia. wire
Drum stiffener corrugation
9 - Openings are approx. 250mm x 430mm
Leave 75mm - 150mm wide sections uncut
Std. 204 litres oil drum
Flexible rubber hose section
Float
INSTALLATION IN DEEP WATER
NOTE:
All screens shall be installed below minimum flow level, shall be easily accessible for cleaning, and shall be cleared of debris at regular intervals.
NOTE:
1. Oil drum shall be thoroughly washed out or steam cleaned before cutting openings.
2. All loose rust shall be removed and the drum coated with metal primer. Two coats of machinery enamel or epoxy paint shall be applied before covering with wire cloth.

Figure 10.10 *Intake screens for pumps with capacities less than 2050 litres per second (ie. one cubic foot per second, 450 U.S. or 375 IMP. gal. per minute). Adapted from Department of Fisheries of Canada (DWG No. 4-3-4 1965).*

11. EXTENSION OF SALMONID DISTRIBUTION

Obstructions to migration frequently restrict the distribution of anadromous salmonids (Fig. 11.1). Where obstructions are impassable, areas downstream may be overcrowded with spawners or juvenile fish while suitable areas upstream lie unused. Even a partial obstruction which poses a barrier under certain flow conditions, can be a serious problem. Many salmonid populations must travel hundreds of kilometres to their spawning grounds, and the time to complete that migration is limited. On entering freshwater, most maturing fish stop feeding, and must rely entirely on energy reserves stored in body fat and protein to carry them through migration and spawning. Rate of sexual maturation and time of spawning are established by heredity, and cannot adjust to delay. Obstructions which cause excessive delay and energy expenditure, can therefore result in mortality either on the migration route or in the spawning stream.

Increasing the utilization of spawning and nursery areas above natural and man-made obstructions is a sound approach to enhancement which has met with considerable success. A large portion of the sockeye salmon production from the Fraser and Skeena Rivers is due to alleviation of obstructions, through either removal of landslides which blocked migration routes, or by construction of fishways. In addition, improved access generally benefits more than one species. A note of caution must be included, however, to cover situations in which newly-created access for one species may result in competition with a species or population already established in the area above the obstruction. Possible species interactions might include steelhead versus non-anadromous rainbow trout, or coho salmon versus established populations of cutthroat or steelhead trout. Though competition with the introduced species will reduce the production of the established species or population somewhat, total production of salmonids normally increases when additional species are able to utilize an area.

In British Columbia the potential for benefit from alleviating obstructions to migration is high, but in many cases the costs outweigh the benefits to be gained. Each situation must therefore be evaluated.

Obstructions to Adult Migration

Natural obstructions may result from log jams, landslides, beaver dams and waterfalls. Man-made dams and improperly installed road culverts are also widespread problems. It is sometimes difficult to establish whether a particular obstruction is, in fact, blocking fish migration. Some partial obstructions can be negotiated only under certain flow conditions, which may not occur every year.

Before any project is planned, salmonid utilization of the stream above the obstruction should be assessed. Visual observations of spawners, or sampling for the presence of juveniles, should be conducted to establish whether or not the area is presently utilized.

Figure 11.1 *Sockeye salmon jumping at rock obstruction in the Tahltan River in northern British Columbia. Injuries and delays due to obstructions on the migration route can cause mortality or reduced spawning success.*

The key physical characteristics of the stream which affect salmonid migration should also be understood before any attempt is made to remove or modify an obstruction. The low waterfalls, inclines and chutes that occur frequently in natural watercourses affect fish migration in several ways (Fig. 11.2). When water drops vertically into a pool with a depth of at least 1.25 times the height of the drop, fish have very little difficulty in jumping over the low obstruction. The upwelling from flow plunging into the pool will actually assist the fish by imparting an upward force as the fish leaps from the pool. On the other hand, a low waterfall with insufficient plunge pool depth will form a hydraulic jump further downstream, encouraging fish to jump too far from the crest of the drop.

Three types of inclines are shown in Fig. 11.2. The relatively flat incline with moderate velocities and without a standing wave or hydraulic jump poses no barrier to fish, whereas the steeper inclines create undesirable hydraulic conditions for both juvenile and adult salmonids.

The following sections describe various approaches to overcoming both natural and man-made obstructions.

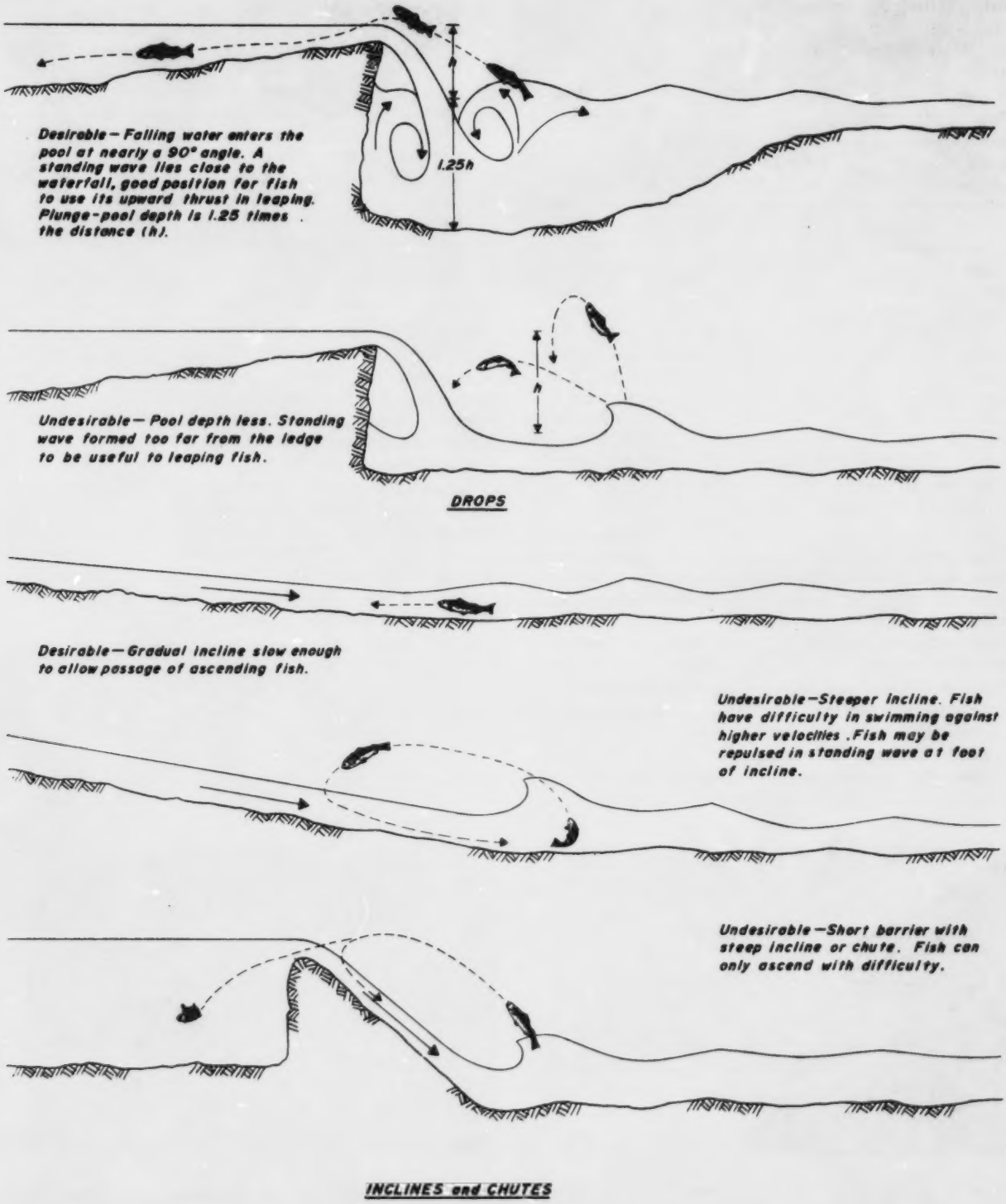

Desirable – Falling water enters the pool at nearly a 90° angle. A standing wave lies close to the waterfall, good position for fish to use its upward thrust in leaping. Plunge-pool depth is 1.25 times the distance (h).
1.25h
Undesirable – Pool depth less. Standing wave formed too far from the ledge to be useful to leaping fish.
DROPS
Desirable – Gradual incline slow enough to allow passage of ascending fish.
Undesirable – Steeper incline. Fish have difficulty in swimming against higher velocities. Fish may be repulsed in standing wave at foot of incline.
Undesirable – Short barrier with steep incline or chute. Fish can only ascend with difficulty.
INCLINES and CHUTES

Figure 11.2 Movement of fish over natural and manmade obstacles (Adapted from White and Brynildson, 1967; diagrams after Stuart, 1964).

Obstruction Removal

Natural Obstructions

The most common natural obstructions encountered in the coastal streams of British Columbia are waterfalls and rapids. A natural rock slide may only partially block a river, yet convert a formerly negotiable section to an impassable torrent.

Rock and earth slides often occur during the fall and spring freshets which may also coincide with the major fish migrations. It is imperative, therefore, that the slide be removed or remedial work be carried out immediately to avoid harmful delay of the run. Often only a partial removal can be carried out due to high stream levels. Under these circumstances, the major portion of the obstruction would be removed when stream flow recedes. Large natural slides, such as occurred on the Babine River in 1951 and the Tahltan River in 1964, required immediate remedial measures to provide fish passage. In the case of the Babine Slide a major undertaking of men and large earth-moving equipment was eventually required to completely remove the obstruction. To avoid delays of migrating salmon at the Tahltan River slide (Figs. 11.3 and 11.4), the fish were lifted by helicopter to a point above the obstruction while remedial work was being carried out to improve fish passage.

However, not all rock slides and waterfalls require the use of heavy equipment and large amounts of capital to improve fish migration. Often small slides can be removed by manual effort and a few simple tools. Summarized below are a few basic techniques that have been used to clear or bypass isolated blockages with a minimum amount of sedimentation and disturbance to the stream.

(1) Selective hand removal or relocation of rocks and boulders can provide a relatively low velocity passage through or around an obstruction. A strong steel bar can be used to hand pry and roll the rocks and boulders into a pattern that will provide a water passage negotiable by fish.

(2) Large rocks and log debris may be removed and/or relocated utilizing slings with block and tackle. Recreational truck winches can be used to advantage for this operation when access is available by road.

(3) Large boulders may be reduced to a size that can be readily removed, using a portable gas-powered rock drill and *feather and wedges* (hand rock-splitting tools). This may also be done with explosives if a qualified blaster is available.

(4) Debris, gravel and small rocks can be removed with hand tools and transported from the river channel in wheel barrows. Where access to the stream is limited, the waste material can be loaded into burlap or canvas bags and removed by slings to a disposal area utilizing an aerial cable-trolley system.

Where it may not be feasible to remove the obstruction, a temporary *pool* and *step* access around or through the obstruction can be constructed by hand placement of sand bags and rock to form the steps of a crude fishway. Often selective blasting, combined with handwork described earlier, will provide a more stable access for fish passage (Figs. 11.5 and 11.6).

Removal of an obstruction during egg incubation could cause serious mortality by silting of the spawning bed. In such a case, a temporary bypass would provide an immediate solution to fish migration while minimizing the damage to the river below. The obstruction can then be removed at a more suitable time, often with the help of the river's natural flood-erosion cycle.

Hand methods of obstruction removal can also be assisted by use of local construction and logging equipment. Weekend use of bulldozers, front-end loaders, and air compressors may be available to non-profit clubs and organizations to assist with stream enhancement projects. If the owners or operators of the equipment take an active interest in the project, use of the equipment could be

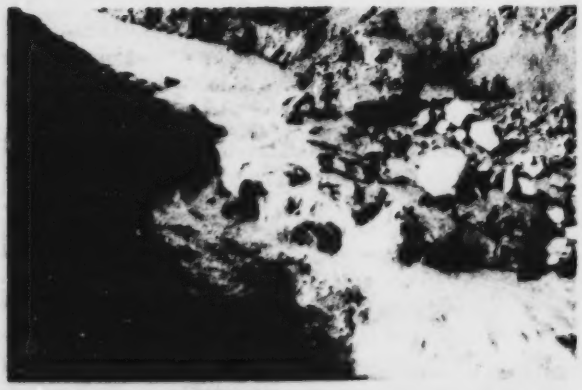


***Figure 11.3** An aerial view of an isolated section of the Tahltan River slide which formed an impassable barrier to adult sockeye salmon migrating upstream.*

***Figure 11.4** While remedial measures were being carried out to improve fish passage around the Tahltan River slide, adult salmon waiting to migrate upstream were air-lifted by helicopter to a point above the obstruction.*

Figure 11.5 A natural obstruction to migrating salmonids. The high velocities developed over the steep bedrock made fish passage impossible at all flows.

Figure 11.6 The same section of stream shown in Figure 11.5, with a simple pool and step access blasted into the bedrock to improve fish passage.

donated or provided at bare operating cost.

A typical man-made obstruction that completely blocked fish passage occurred on a northern Vancouver Island stream during construction of a logging road (Fig. 11.7). This slide was removed from a narrow section of the river with a logging yarder, combined with selective blasting and some handwork. The slide temporarily blocked a large portion of the coho salmon run to the upper reaches, and silted downstream pink salmon spawning areas.

Figure 11.7 Construction of a logging road caused rock overburden and debris to block a major fish producing river on northern Vancouver Island. Selected hand work combined with the use of a logging yarder removed most of the slide and restored passage to upstream migrating salmonids.

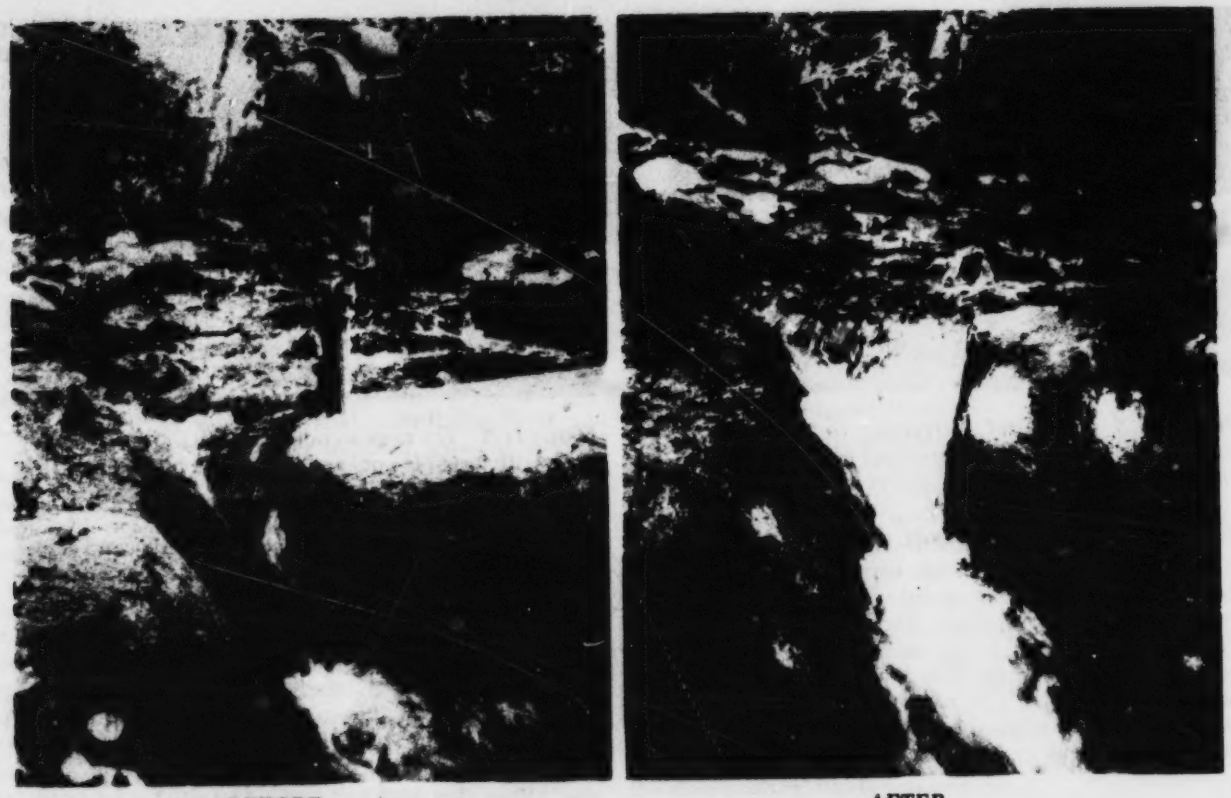
On a much smaller scale, a natural obstruction in a stream channel may only consist of a narrow bedrock restriction which creates a velocity barrier to migrating fish. For the example shown in Fig. 11.8, flow through the rock restriction was improved by simply drilling three holes with a portable drill along one edge of the restriction and splitting the rock to create a wider channel. Even though a hydraulic chute still existed upon completion of the work, the wider channel and reduced turbulence improved fish passage conditions.

Log Jams

Another form of obstruction, which can be either man-made or natural, is the log or debris jam. It is sometimes difficult to establish whether a log jam is blocking migration. Often a log jam which appears impassable has stable underwater passages for migrating fish. Log jams are known to be preferred rearing habitat for steelhead trout and coho salmon, because of the excellent cover they afford. Large, stable pools created by log jams provide holding areas for adult salmonids.

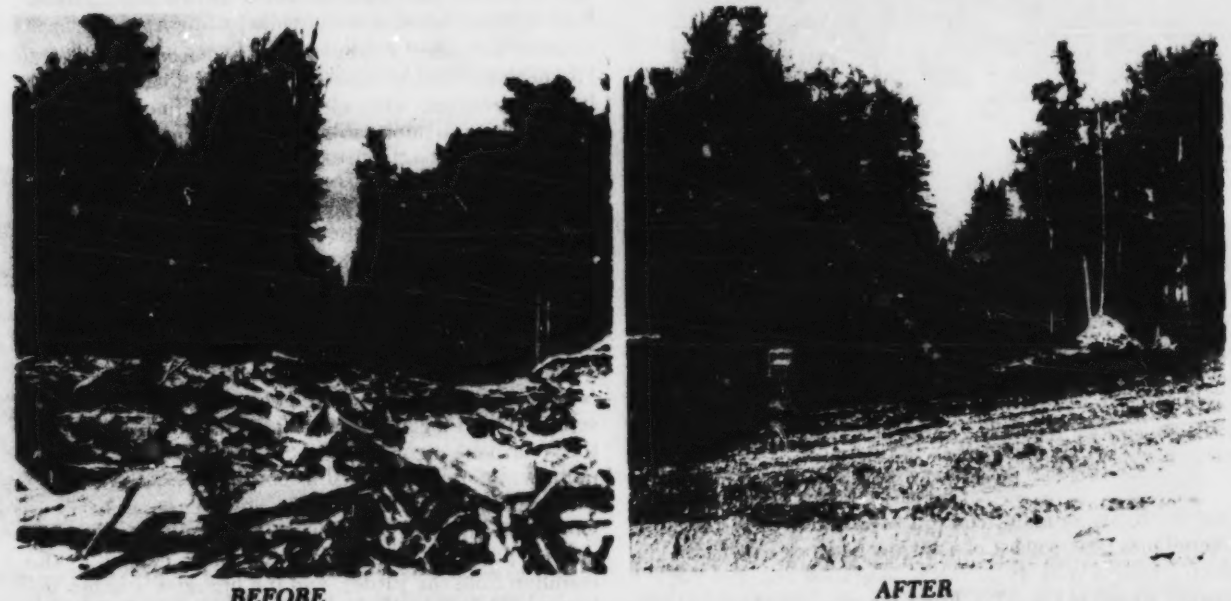
Certain log jams, however, prevent access to several kilometres of usable stream. Log and debris jams which become plugged with silt, gravel and fine debris can actually form an impassable waterfall. A log jam located in the upper reaches of a stream, and naturally isolated from fish by one or more waterfalls, is often overlooked as a potential problem. The logs may be loosely jammed in a narrow canyon, and during freshet conditions could break loose and create havoc downstream. Breakup of such a log jam can plug or damage stable, beneficial log jams, and partially submerged logs, or *sinkers*, can scour spawning areas downstream.

There are several methods for removing log jams. If access is available, the most efficient method is to use a self-propelled logging yarder. The machine is set up on the river bank on one side of the log jam, and an anchor point with a pulley is established on the opposite bank. The machine operates like a high speed *clothes line*. Men wrap cable chokers (slings) around the logs and bundles of debris, hook the free end of the cable choker to the mainline from the yarder, and the operator winches the logs and debris to the machine where the chokers are released. The mainline is then reversed and the empty



BEFORE AFTER

Figure 11.8 Narrow notch in stream channel forms a velocity barrier to migrating fish. Fish passage was improved by drilling three holes with a gasoline-fuelled rock drill and splitting the bedrock which formed the sides of the notch.



BEFORE AFTER

Figure 11.9 A log jam completely blocked a river channel. The logs and debris were removed with a large bulldozer and disposed of by burning. Silt and sand which accumulated against the logs was also excavated and removed from the main river channel.

BEFORE *AFTER*

Figure 11.10 *Small log jam which created a velocity barrier to migrating salmonids. Logs, stumps and debris could be readily removed by hand using power-saws and block-and-tackle.*

chokers are hauled back to the men dismantling the jam. Very large jams can be removed quickly and cleanly with a cluster of lightweight chokers. After the jam is removed the large pile of debris can be burned when weather permits.

When logging equipment is not available and access to the site is poor, manual labour combined with a selective power-saw operation can be used to dismantle a log jam. Often a four-wheel-drive vehicle, fitted with a winch, can assist in removal of logs and debris.

There are several other methods for removal of log jams, but they are basically modifications of those described above, using different types of equipment. Log jams can also be removed by blasting, but due to the inherent dangers of suddenly releasing a major jam, this method should only be used under the supervision of a fisheries management agency. When explosives are used to remove a log jam, considerable handwork is required to selectively weaken the mass of tangled stumps, logs and debris prior to detonating the explosives. Long trees are cut into shorter lengths and stumps or logs which penetrate the channel sides are also cut with powersaws to weaken the entanglement of logs and debris.

The major log jam shown in Fig. 11.9 blocked an entire river channel for several hundred feet. The jam was carefully removed by a large bulldozer, and the debris was disposed of by burning. Silt and sand which had accumulated in the log jam was excavated and removed from the channel to minimize siltation of downstream spawning areas.

The smaller log jam shown in Fig. 11.10 created a velocity barrier to migrating fish. When jammed against bedrock outcrops in the channel bottom the logs created a stream section of very high velocity. A jam of this size could be readily removed by hand, using power-saws and block-and-tackle.

Figure 11.11 shows a log jam which bridges the stream and does not obstruct the flow or pose a barrier to migrating fish. This type of log jam, which is beneficial to both rearing and spawning salmonids, should not be removed.

Beaver Dams

Beaver dams can also create obstructions to migrating fish (Fig. 11.12). A comparison can be made to log jams discussed earlier in that not all aspects of beaver dams and their associated head ponds are detrimental to salmonids. Rearing juveniles will utilize the beaver pond. In addition, the pond can provide storage which stabilizes stream flows, augmenting the groundwater contribution to a stream's base flow, as well as reducing peak flows during freshet conditions. In Section 14 of this guide it will be shown how the stored water behind a beaver dam can be

Figure 11.11 *This log jam is beneficial to salmonids. It provides cover and holding areas for rearing juveniles and does not pose a barrier to upstream migrating adults.*

***Figure 11.12** Aerial view of beaver dam and associated impoundment. Only beaver dams that are detrimental to fish habitat should be removed.*

released on a controlled basis to augment critical low flows.

Beavers are hard working and persistant animals. When either a portion or all of a beaver dam is removed the beaver family will normally attempt to restore the damaged structure. Invariably, they succeed.

One of the approaches taken to maintain fish passage through a dam is to open only a portion of the crest during the fish migration period. This often results in a daily battle with the beavers to maintain an opening. Alternatively, the beaver dam can be entirely removed, with particular attention to hand removal of all anchor-sticks embedded in the stream bottom. In addition, all food caches and debris lodged in the bottom behind the dam should be removed to allow silt to be adequately scoured away. In some cases the beaver may have to be trapped and transported to another site to minimize the chance of dam reconstruction. Fish and Wildlife Branch approval would then be required.

Since complete removal of a beaver dam will release large quantities of silt to downstream spawning areas, the work must be carried out well in advance of spawning, preferably in early summer after fry have emerged.

Beaver dams can be breached with either simple hand tools, a small backhoe (if access is available), or by blasting. Removal of a beaver dam by blasting should be carried out only by persons skilled in the use of explosives, and with the permission and guidance of the regulatory agencies. Extensive hand work is often still required after removal of a beaver dam by blasting.

Where frequent inspection of the beaver dam is possible, it is preferable to maintain an opening for fish passage over the crest of the dam. This results in a minimum of damage to the downstream areas, while still maintaining the beneficial aspects of the impoundment. In cases where the dam and the associated impoundment create temperature problems, or the beavers have abandoned the structure, the dam should be removed.

Fishways

Fishways provide a way past man-made or natural obstructions that impede or bar upstream migration of mature salmonids. The structures generally consist of a flume with baffles or a series of stepped pools that slow the water to a velocity easily negotiated by fish. Fishways may assist fish either to reach traditional spawning areas or to colonize areas previously cut off by a barrier. They can serve any of the salmonids, but are especially helpful to the weaker swimmers such as chum and pink salmon.

Three main types of fishways are used in British Columbia (Fig. 11.13). The *pool-and-weir* type consists of a series of vertical partitions installed at intervals down the length of a specially constructed channel or flume. Water flows over the top of the successive partitions, each slightly lower than its predecessor, creating a series of step-like pools which the mature salmonid can ascend with ease. The pools must be carefully sized to dissipate the energy of the cascading flow. Pool-and-weir fishways are most effective where water levels remain fairly constant. Where water levels fluctuate, they require regular adjustment at the upstream end to provide the optimum rate of flow.

A modification of the weir type of fishway is the *pool-and-orifice* fishway, which includes orifices in the weir (Fig. 11.13). The orifices are normally sized to provide an adequate flow over the weirs in addition to a flow through the orifice. Since the fishway can also operate with all the flow through the orifice, the pool-and-orifice fishway is effective over a slightly greater range of flows than the basic weir fishway. The pool-and-orifice fishway also allows fish to ascend through the fishway without jumping over the weirs.

The *vertical slot* fishway also creates a series of pools and drops, but its flow passes from pool to pool through narrow slows extending the full height of the partitions (Fig. 11.13). The vertical slot fishway is self-adjusting to flow levels. It provides passage for the fish through a range of changing volumes or levels of water in the stream, without requiring adjustment of stoplogs or baffles, as in the case of the weir fishway. This is a great advantage, in view of the extreme discharge fluctuation of most coastal streams and the relative isolation of many fishways.

The *Denil* fishway, a third type used in British Columbia, is essentially a short section of flume with baffles affixed to the sidewalls and floor. The energy of water passing through the structure is dissipated in turbulence caused by the baffles which leave a narrow zone of low-velocity flow. The Denil fishway is particularly suited to situations where most expensive conventional fishways would not be warranted. Denil fishways can be installed at much steeper slopes, and for a given height of obstruction they can be substantially shorter than other types.

A modification of the Denil fishway, the Alaskan *Steeppass*, is smaller, reduces velocities more effectively, can be prefabricated from lightweight aluminum, and is easily installed. This portable type of Denil fishway can be used to assess the potential of a site prior to the installation of a

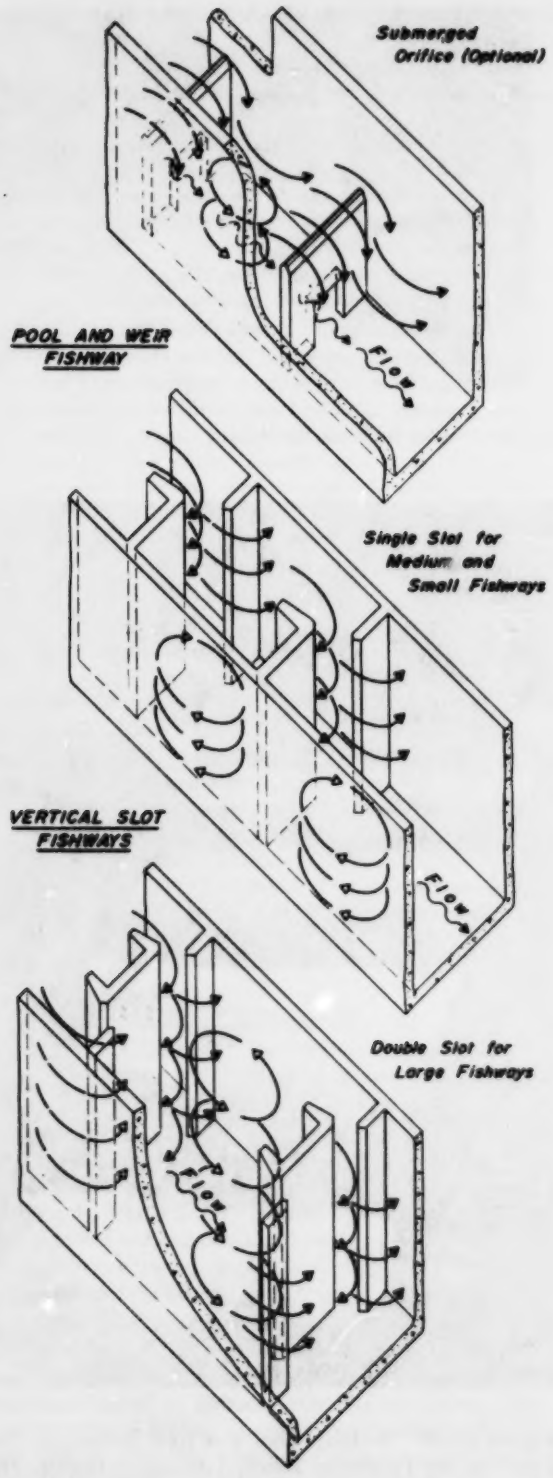


Figure 11.13 General outline and operational characteristics of pool and weir and vertical slot fishways.

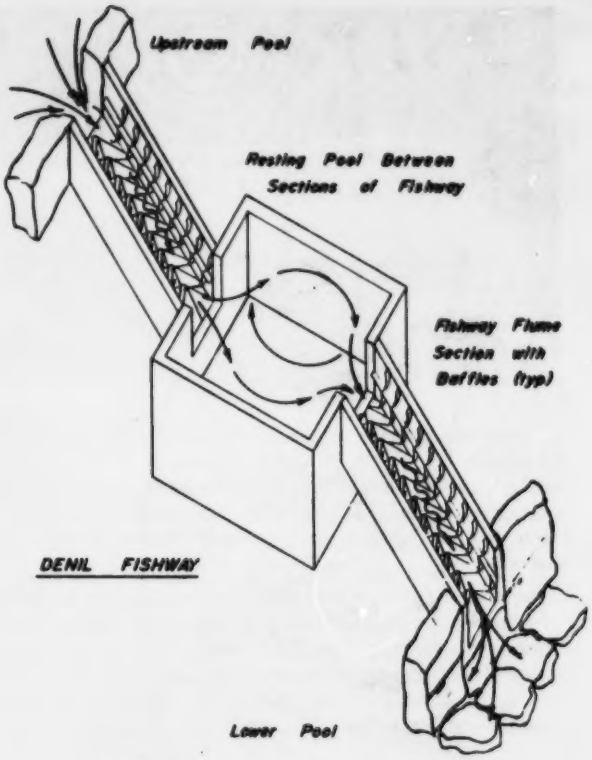


Figure 11.13 (cont'd) General outline and operational characteristics of Denil fishway.

larger and more costly fishway.

Placement of fishway entrance is critical. The fishway entrance should be positioned where fish tend to congregate, normally in the area of greatest flow at the base of the obstruction. Sometimes rock work, a training wall, or even a barrier dam, is needed to divert water and fish toward the fishway entrance (Fig. 11.14).

Successful design, construction and operation of a fishway requires close cooperation between designers and biologists. The principal biological and hydrological information required prior to the design of a fishway is listed below:

- — the species of salmonids in the river system, as well as the magnitude and timing of the runs;
- — the probable access route to the barrier, including the areas where fish will congregate below the obstruction;
- — the extent of spawning and nursery areas and the potential salmonid production from both above and below the obstruction;
- — the type and quantity of anticipated debris;
- — the frequency, duration, timing, and magnitude of various types of flows, especially extreme high and low flows; and
- — the location of other barriers in the stream system, and their possible effects on distribution of salmonids.

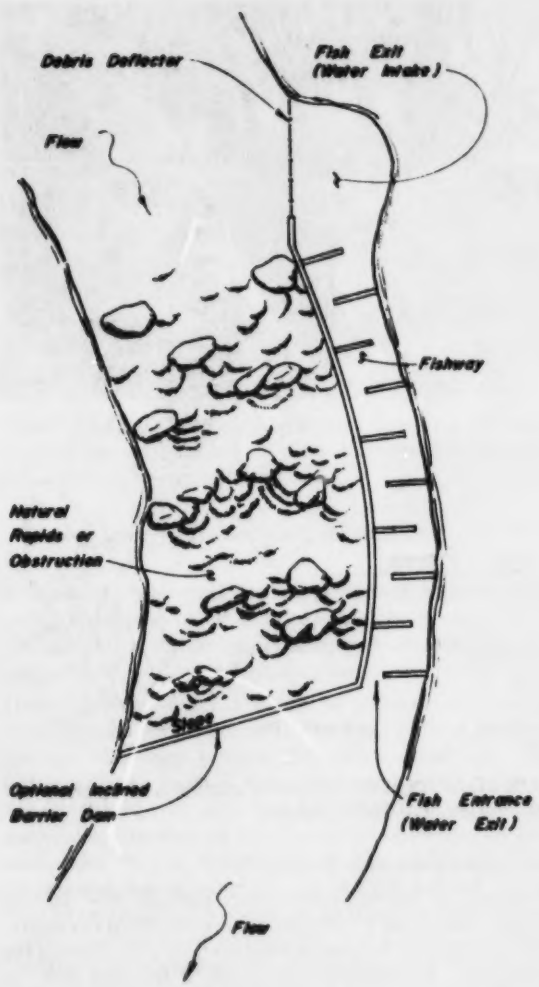


Figure 11.14 Fishway bypassing a natural obstruction. Entrance to the fishway must be located where fish tend to congregate. The fish exit (water intake) should be protected with a debris deflector.

After the preliminary information is gathered, the following points must be considered in locating and designing the final structure:

- the fish entrance should be located as close as possible to the areas where fish congregate below the obstruction;
- flows in and near the fish entrance should be substantial enough to attract fish at all water levels;
- when fish will be swimming through high velocity water, changes in direction should be minimized;
- energy dissipation must be complete, with no carryover from pool to pool;
- the fishway must provide adequate depth for the fish to swim;
- resting spaces must be adequate;
- flow patterns in the fishway must be stable, with no surges;
- a debris deflector should be incorporated at the water intake;
- the upstream exit should be located so fish will not readily be swept back downstream, over the obstruction; and
- the design should minimize the requirements for cleaning, regulating and repairing the fishway.

When fishways are constructed in rock, the native material can often be incorporated into the structure, thereby reducing costs and improving the appearance. Fig. 11.15 shows a small, modified pool-and-weir fishway constructed using bedrock for the basic flume section. The

Figure 11.15 Modified pool and weir fishway at Nib Falls on the Puntledge River, Vancouver Island. The flume section was carefully excavated in solid rock. Concrete baffles with narrow vertical slots were used to form the weirs.

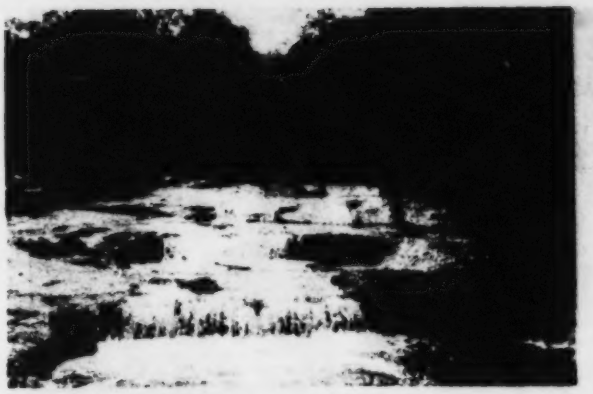


Figure 11.16 Simple pool and weir fishway on the Millstone River, Vancouver Island, constructed by a fish and game club. Steps were formed by selectively drilling and blasting the natural bedrock formations in the stream channels.

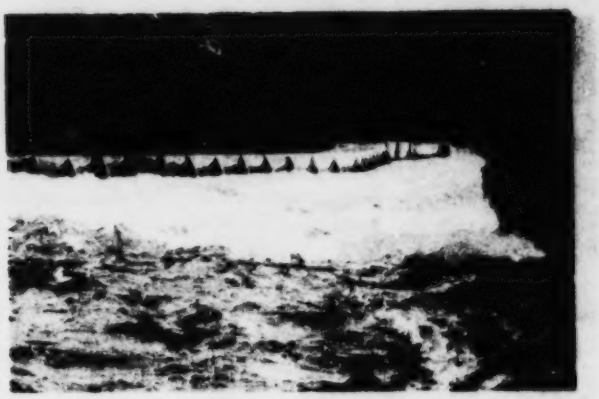


Figure 11.17 Reinforced concrete vertical slot fishway was required to bypass a major falls and rapids at Meziadin River in the Nass River system. Because of the complexity of design and construction, this type of facility is normally undertaken by fishery agencies.

weirs were constructed of reinforced concrete. The flow in this section of the river was relatively stable during fish migration due to the controlled release of water from a hydro-electric diversion dam. The fishway therefore did not have to operate over a large range of flow. The flume section of the fishway was carefully blasted by drilling closely-spaced holes along the sides of the fishway and then preblasting the holes with special explosives prior to excavating the centre rock section. This method of blasting is known as *preshearing* and results in straight rock walls with a minimum of rock overbreak. The concrete baffles, or weirs, were constructed with alternating full height vertical slots to minimize the collection of silt and debris within the fishway. However the slots were small enough for the fishway to operate with adequate flow over the weirs.

Fig. 11.16 shows a fishway constructed by selective blasting of bedrock, to augment the existing natural steps and pools. Often fishways of this type require some concrete in order to replace weak or broken rock.

In reinforced concrete fishways the standard vertical drop between pools is 30 cm. This will vary slightly between installations, depending on the species of fish and the size of the pools. For fishways constructed out of rock and tailored to the natural pools and steps in the rapids section, the drop between pools could vary from as little as 10-15 cm to almost 60 cm.

Fig. 11.17 shows a reinforced concrete vertical slot fishway. This type of fishway will operate over a large range of flows, requires minimal maintenance, and is therefore particularly suited to British Columbia conditions. Because this type of fishway requires considerable technical input, and is relatively complex to construct, it would normally be constructed by the government resource agencies.

The Denil type fishway shown in Fig. 11.18 is a prefabricated aluminum fishway installed as a pilot structure. Runs of 100,000 to 250,000 pink salmon have been observed to ascend the falls to spawn in previously inaccessible areas. Now that it is known that the salmon will move in large numbers above the falls, replacement of the high-maintenance Denil structure with a permanent vertical slot fishway can be justified.

Culverts

Culverts are used in a wide variety of drainage works, and are most commonly installed to convey water under roads, highways and railways. In addition, culverts have been installed for long distances through developed areas to eliminate creeks from view and/or to reclaim land by filling in the majority of the stream channel. In many cases culverts are used in preference to bridge crossings because they are less costly, relatively easy to install, and able to accommodate higher volumes of flow than an equal cross-section of natural stream. This latter feature is due to the fact that a culvert is smoother and usually straighter than the stream channel it replaces.

Culverts are most commonly constructed of wood, concrete or corrugated steel, and are generally either round, rectangular or arch-shaped. Each type has its own particular application, depending on the required size, flow capacity and life expectancy, as well as any restrictions on culvert height.

Poor design and/or installation of a culvert can lead to a fish passage problem. One poorly installed culvert can exclude migratory fish populations from an entire stream system. The factors governing fish passage through a culvert are the water velocity and depth in the culvert, length and slope of the culvert, entrance and exit conditions, and the size and species of fish using the stream.

As different species and sizes of fish vary in their swimming ability, a culvert installation can be a species-selective barrier to upstream movement of both adult and

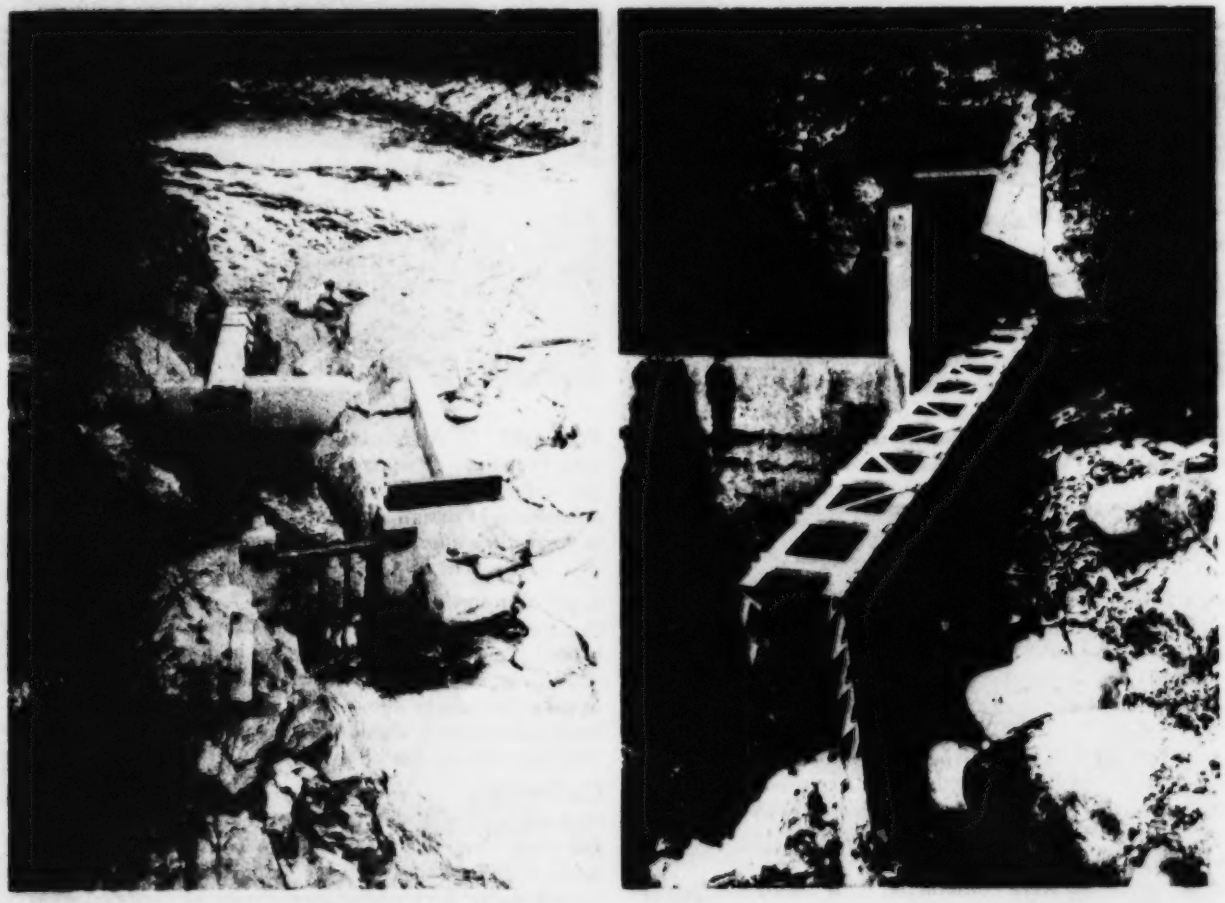


Figure 11.18 Denil style fishway on the Kakweikan River (left) constructed from prefabricated aluminum sections. This is basically a temporary structure to provide fish access to under-utilized spawning area above the falls. A permanent reinforced concrete vertical slot fishway will be constructed in the future. The same type of fishway (right) was used by a fish and game club to provide access over a culvert obstruction on a small creek.

juvenile fish. When populations of salmonids and other species occur together, the swimming abilities of all species potentially affected by a culvert installation must be considered.

Within its natural environment a fish uses a variety of speeds ranging from a sudden, swift movement or darting motion to a lazy wandering movement when at rest. Most researchers agree that the swimming performance of fish can be divided into three categories or levels of performance: burst (darting) speed, sustained (prolonged) speed, and cruising speed. Burst speed is defined as that normally employed by a fish for feeding or escape purposes; sustained speed is for normal movement such as migration. These definitions are, perhaps, best applied to the upper limit of each category, in which case the burst speed would correspond to the maximum swimming speed of the fish.

Summarized below are a few general comments concerning the design of culverts and fishways relative to these three categories of swimming performance.

Burst Speed

Burst speed is defined as the speed which a fish can maintain for a very short period of time, generally 5-10 seconds, without gross variation in performance. Burst speed is representative of the speed that would be used for fishway design as it would determine the velocity limit that could be tolerated at the fishway slot. Accordingly, its application to culvert design would be limited to those culverts in which a fishway is constructed to assist fish in entering the culvert.

Sustained Speed

Sustained speed can be defined as the speed that a fish can maintain for a prolonged period, but which ultimately results in fatigue. As this definition suggests, the fish is under some degree of stress while maintaining this rate of travel. The sustained speed capability is most applicable

to culverts, because of the usual high velocities and the lack of resting areas. To pass through a culvert, fish must maintain an above-normal level of activity for an extended period of time. Some species of salmonids can swim at the sustained speed for 300 to 500 minutes.

Cruising Speed

The cruising speed can be defined as the speed which a fish can maintain for an extended period of time without fatigue. Cruising speed therefore does not enter into the design of fish passage facilities and need not be considered further in discussion except to note that any speed in excess of cruising speed places stress on the migrating fish.

Table 2 outlines swimming performance levels for various species of adult fish. The sustained swimming speeds listed in the table can be used to develop guidelines for culvert installations.

Using the known sustained swimming speed of a species, one can construct a graph to determine if passage through a culvert is possible under a given set of conditions. One such graph is presented in Fig. 11.19, which shows the relationship between water velocity and permissible culvert length for various species of fish. Although these relationships are based on limited test data and other assumptions that simplify their development, the values obtained from the curves do represent a good estimate of swimming ability for adult fish in their environment.

To ensure that fish populations are not adversely affected by the interruption of upstream migration at a culvert site, certain hydraulic conditions must be met and maintained throughout the migration period. In this regard, the provincial and federal fisheries agencies have prepared guidelines for installing culverts. The general requirements have been summarized in Table 3.

These guidelines for culvert installation are based on the upstream migration of adult fish. However, in some British Columbia streams juvenile salmonids may also seek to move upstream at certain times. Such migration may result from changes in habitat requirements with season, eg. seeking sheltered areas such as side channels or lakes to overwinter, or may be due to population pressures.

Since the migration periods for juvenile salmonids are not normally confined to the narrow time span associated with spawning adults, the passage of juveniles through a culvert can often be delayed without harm until discharge recedes. However, for some streams a culvert that has been designed to accommodate adult migration must also provide for passage of juvenile salmonids at lower flows. In some very critical situations, such as where small sockeye salmon or trout fry must migrate upstream to a lake, the basic choice between a culvert and a bridge may require careful assessment.

One of the most common fish passage problems associated with culverts is the formation of a drop at the downstream end (Fig. 11.20). This is caused by either improper installation or continuing scour of the stream bed. To minimize this problem, culverts are best placed where the stream gradient approaches zero and the velocity is uniform. Where drops have formed at the downstream end of existing culverts, the problem can be corrected by backflooding with weirs or cribs set downstream. These can often be constructed using gabions (wire baskets filled with rock) or large interlocking pieces of quarry rock (Fig. 11.21). Log drop structures, well anchored on either end

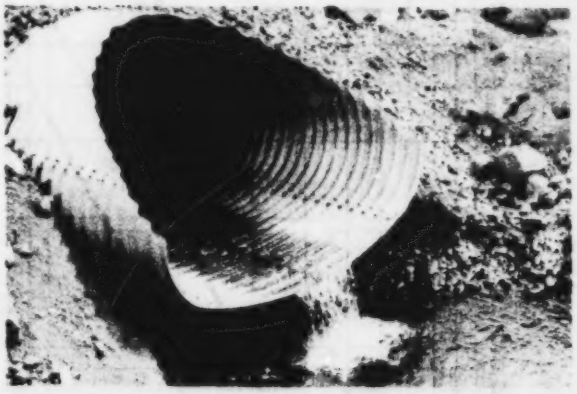


Figure 11.20 *Formation of a drop at the end of a culvert is one of the most common obstructions to migrating fish. Passage can be improved by backflooding the culvert with a weir to provide a* ***jump pool****.*

Table 2. Swimming speeds for average-sized adult fish of various species (metres/sec). (Adapted from Dane, 1978).

Species	Cruising Speed	Sustained Speed	Burst Speed
Brown Trout	0 - 0.7	0.7 - 1.9	1.9 - 3.9
Carp	0 - 0.4	0.4 - 1.2	1.2 - 2.6
Chinook	0 - 2.7	2.7 - 3.3	3.3 - 6.8
Coho	0 - 2.7	2.7 - 3.2	3.2 - 6.6
Grayling	0 - 0.8	0.8 - 2.1	2.1 - 4.3
Lamprey	0 - 0.3	0.3 - 0.9	0.9 - 1.9
Shad	0 - 0.7	0.7 - 2.2	2.2 - 4.6
Sockeye	0 - 1.0	1.0 - 3.1	3.1 - 6.3
Steelhead	0 - 1.4	1.4 - 4.2	4.2 - 8.1
Suckers	0 - 0.4	0.4 - 1.6	1.6 - 3.1
Whitefish	0 - 0.4	0.4 - 1.3	1.3 - 2.7

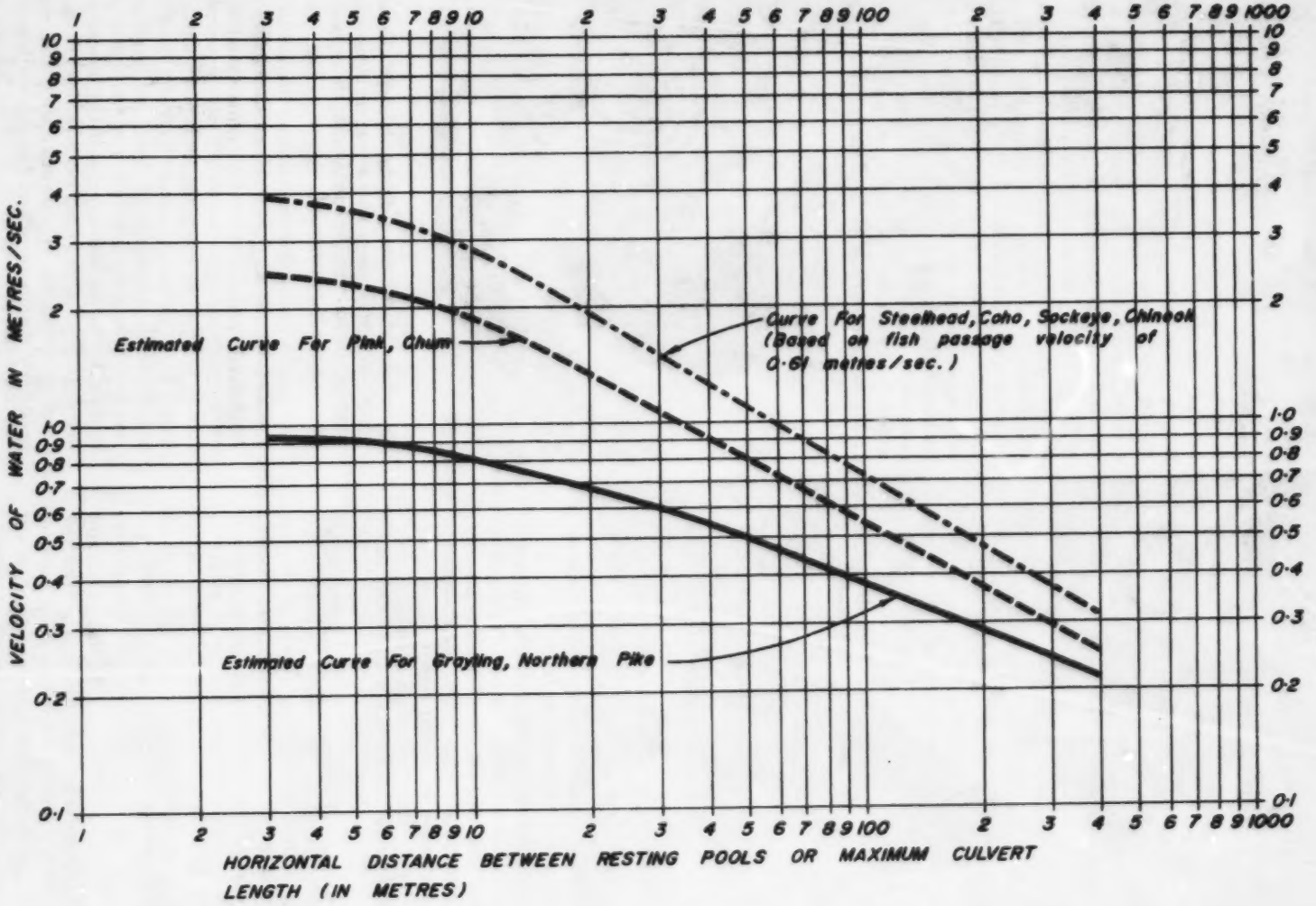

VELOCITY OF WATER IN METRES/SEC.
HORIZONTAL DISTANCE BETWEEN RESTING POOLS OR MAXIMUM CULVERT LENGTH (IN METRES)
Estimated Curve For Pink, Chum
Curve For Steelhead, Coho, Sockeye, Chinook (Based on fish passage velocity of 0·61 metres/sec.)
Estimated Curve For Grayling, Northern Pike

Figure 11.19 *Swimming Capability of Migrating Fish in Fresh Water. (Source: Fisheries and Marine Service Technical Report No. 810. Adapted from Ziemer, G.L., 1961. "Fish Transport in Waterways". Alaska Dept. of Fish & Game).*

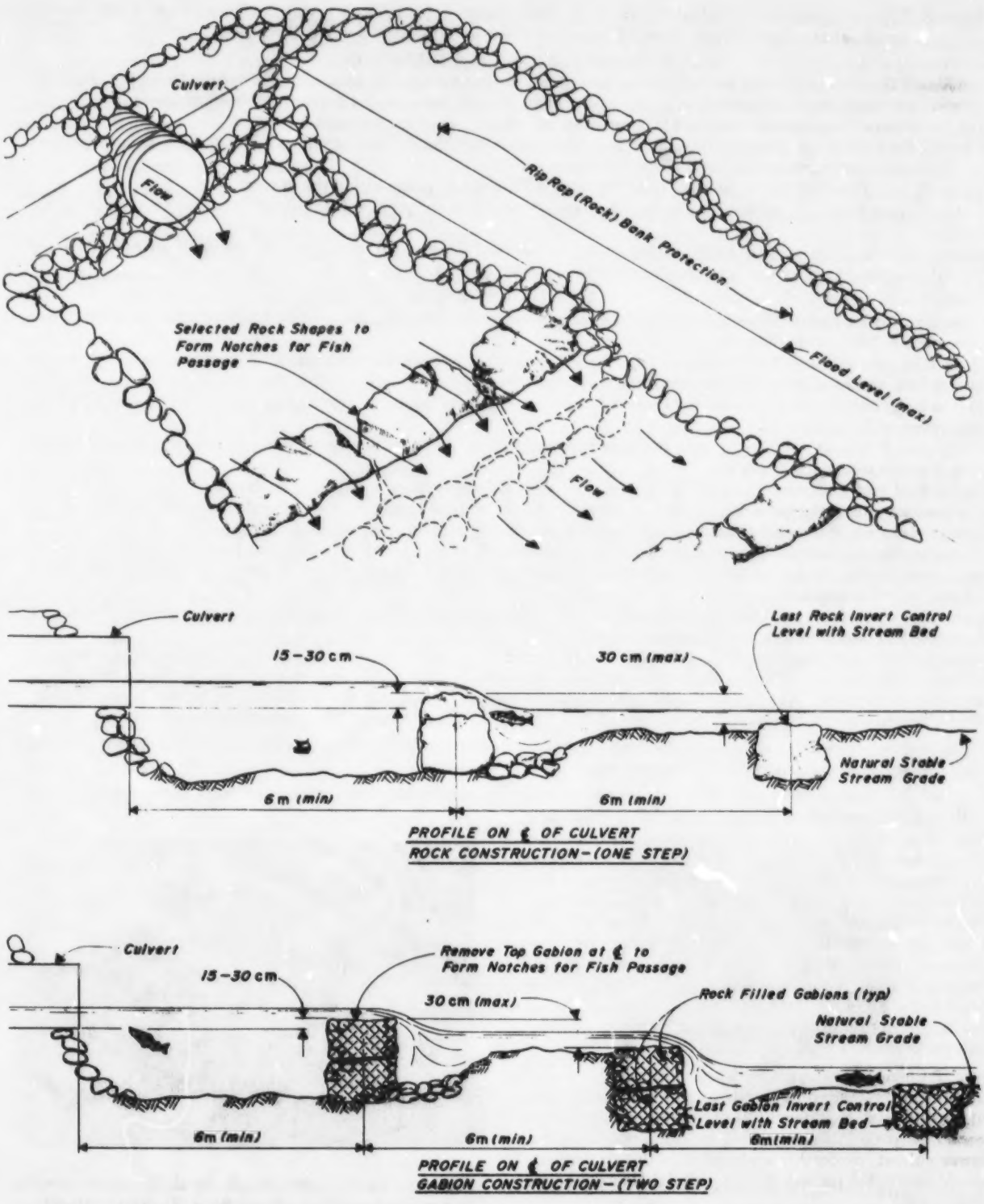


Figure 11.21 *Back flooding a culvert to eliminate the downstream drop to improve fish passage. The banks and stream bed must be stabilized with large rock (rip-rap) or rock filled gabions.*

Table 3. Culvert design and installation guidelines (from Dane, B.G. 1978. A review and resolution of fish passage problems at culvert sites in British Columbia. Fisheries & Marine Service Tech. Rept. No. 810).

FISH MIGRATION REQUIREMENTS

Velocities. The average water velocity in the culvert should not exceed the following values (developed from Fig. 11.19).

— For culverts less than 24.4 long, average velocity should not exceed 1.2 m/sec (metres per second).

— For culverts greater than 24.4 m long, average velocity should not exceed 0.9 m/sec.

— For culverts greater than 61 m long, special consideration should be given to each site, and the fisheries agency should be consulted.

Water Depth. Depth of water should not be less than 0.23 m at any point within the culvert.

Water Surface Profile. A sudden drop in the water surface profile at any point within culvert influence should not exceed 0.31 m.

Migration Delay. During upstream fish migration, the period during which the foregoing conditions are *not* met at the culvert site should not exceed 3 consecutive days in an average year.

DESIGN CRITERIA

Capacity. Culvert facilities should be designed to accommodate the 100-year flood, defined as the discharge event having a recurrence interval of 100 years.

Slope. The effective slope* of the culvert at any point along its length should not exceed 0.5% for a culvert greater than 24.4 m long, unless appropriate compensation is made by the addition of baffles within the culvert. In culverts less than 24.4 m long, effective slope should not exceed 1% unless baffles are added. Culvert slope should not exceed 5% at any time, even with baffles.

Installation Below Grade. The culvert should be installed so that the bottom of the structure is at least 0.31 m below the natural grade line of the stream.

Outlet Pool and Tailwater Control. An outlet pool with tailwater control capabilities should be constructed at the downstream end of the culvert. Length and width of the outlet pool should be twice the diameter of the culvert, and bottom elevation of the pool should be at least 0.6 m below culvert invert elevation at the outlet.

The crest elevation of the tailwater control device should be sufficient to provide a minimum depth of 0.23 m throughout the culvert during the lowest stream discharge anticipated, or at least 0.23 m above the lowest elevation in the culvert fishway or baffle structure.

A small notch or depression should be provided at the tailwater control device to ensure that a passageway of sufficient depth for fish migration is available at minimum flows.

Culvert Baffles and Fishway. Baffles should be constructed in the culvert barrel if the slope of the culvert exceeds the criteria outlined above. Offset baffles are recommended for this purpose and are described later in this guide.

Multiple Installations. When more than one culvert is provided, fish passage criteria need only be applied to one of them. The culvert to which fish passage criteria are applied should be installed at least 0.31 m lower than the other culvert(s).

*Effective slope is defined as the mean gradient of the water surface profile between a point located at the culvert inlet and the tailwater control point below the culvert outlet.

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with rock and notched in the middle for fish passage, are also effective in maintaining the water level at the downstream end of a culvert. However, since backflooding normally reduces water velocity, the capacity of the culvert can be oversized initially to offset this condition. For existing installations the culvert capacity can often be restored to its original level by streamlining the upstream entrance to the culvert using diverging wing walls, and by making provisions for the culvert to surcharge during flood flows. Surcharging can be accomplished by raising the height of the fill entrance walls above the top of the culvert to create a higher upstream water level.

Another method to improve fish access is to place two or more culverts at different elevations above the streambed to accommodate a wider flow range. The higher culvert would be capable of conveying peak flows, while the lower culvert, preferably embedded in the streambed, would ensure fish passage during periods of low discharge (Fig. 11.22).

Fish passage at the upstream end of a culvert can also be impeded by improper transition from culvert flow to

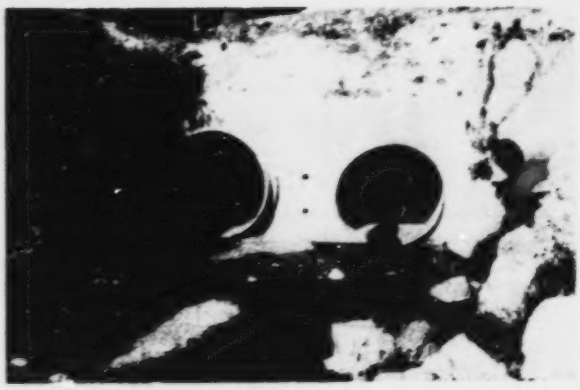


Figure 11.22 *Culverts installed at different elevations to improve fish passage at lower flows. The right culvert was installed with the invert below the river bottom to ensure fish access.*

stream flow. In this regard, it is desirable for fish to enter a low velocity resting area as soon as they have passed through the culvert. Pools at the entrance to culverts are difficult to keep free of bedload. However, if large rocks are placed upstream of the culvert, the back-eddy behind each individual boulder will form a resting area for migrating fish. The rock should be located to avoid trapping debris and backwatering the stream.

Blockages due to debris at the upstream end of a culvert can also stop fish migration. This situation is most prevalent in undersized culverts. Other than installing a larger pipe, regular maintenance of the system would be required. Trash racks embedded in the stream bed upstream of a culvert, if not maintained, only delay the debris problem and often impede the passage of fish as well. Generally it is better to install an oversized culvert to pass the debris rather than trashracks.

It is often necessary in large culverts, where the velocities are high or the bottom of the structure is very wide relative to the available low flow, to install baffles on the bottom of the culvert (Figs. 11.23 and 11.24). These baffles, which are usually made of concrete or treated timber, create depths and velocities suitable for fish passage at low flows. In existing corrugated metal culverts, threaded rods can be welded or lag-bolted to the bottom to enable treated timber sills to be bolted directly to the pipe. Alternatively, reinforced concrete can be used where reinforcing dowels are welded to the culvert floor instead of bolts. In existing concrete culverts, holes can be drilled in the floor and rods or bolts can be grouted into place. In new culverts, provisions can be made in advance, by installing bolts and reinforcing dowels when the structures are built. The cost of installing baffles at time of construction is considerably lower than for an existing facility.

Several different baffle arrangements have been investigated. Experiments have been carried out to compare performance of paired and alternating baffles of equal length, and offset baffles. Of the three types investigated, offset baffles (Fig. 11.25) produced good flow patterns and fish passage at culvert slopes of up to 5%. At flood flows, the self-cleaning properties of offsetbaffles were positive and complete. It was also found that baffles were most effective for fish passage when their height was 30 cm or greater and water depth just overtopped the baffle.

Offset baffles are normally installed in rectangular culverts not less than 1.2 metres wide. For circular culverts, a minimum diameter of 1.5 metres is required. In smaller culverts without a flat bottom, horizontal baffles occupying the entire width are often installed. In very large culverts a 30 cm high separator wall can be installed as shown in Fig. 11.25. This baffle system is normally used in culverts more than 2.2 metres wide. Incorporating a separator wall into a baffle system has been shown to improve a culvert's operating performance over a wider range of flows.

With careful design and choice of location a culvert need not impede fish. However, many culverts are installed to pass water quickly and efficiently, not to pass fish upstream. When the total costs of correcting such installations are considered, the installation of other structures such as bridges and arches would often have been more attractive. Alternatives to culverts should therefore be considered, both from a bio-engineering and economic point of view, if fishery resources are to be protected. If alternatives are not viable, then fish passage devices within the culvert, combined with upstream and downstream improvements, should be provided.

Establishing Populations

Anadromous salmonids may be slow to take advantage of stream areas made accessible by the alleviation of an obstruction. This problem arises particularly where an obstruction has historically been a complete barrier to

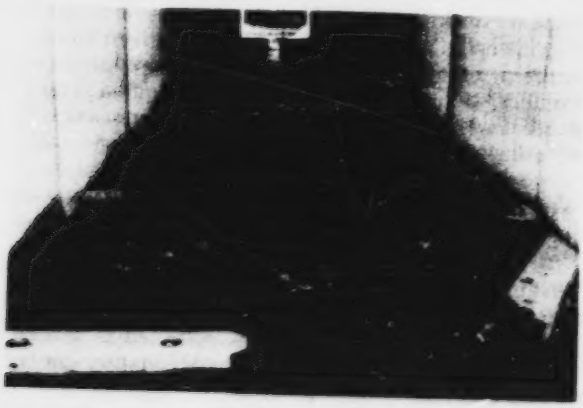


Figure 11.23 Concrete rectangular culvert with offset baffles bolted to the floor. The baffles were made of treated timber. Without them water velocities would be too high and the depth too shallow during fish migration.

Figure 11.24 Corrugated metal culvert with reinforced concrete baffles. Reinforcing dowels are welded to the floor of the culvert to anchor the baffles.

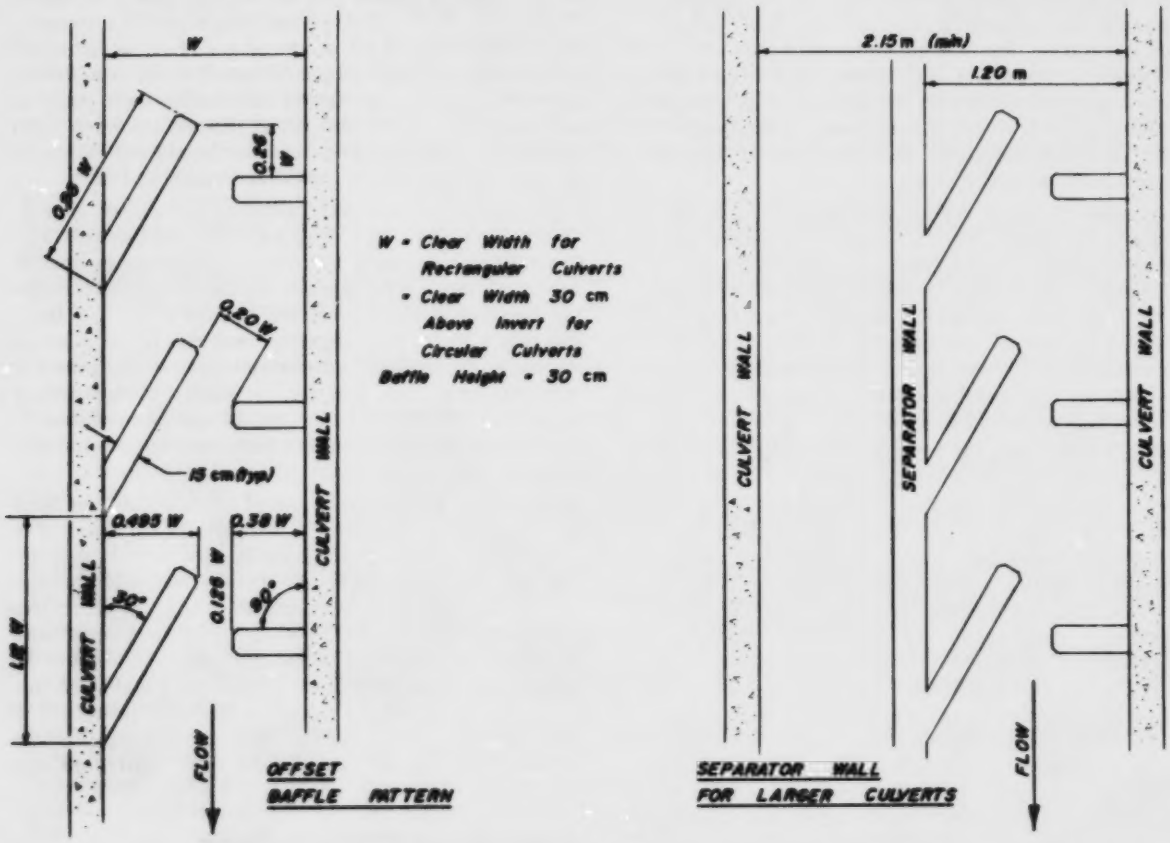


Figure 11.25 *Fish passage through culverts can be improved by installing offset baffles on the bottom of the structure. Divider walls can be used in conjunction with offset baffles for culvert widths exceeding 2.15 metres.*

migration. In these circumstances, the populations downstream of the barrier may not have acquired behavior conducive to colonization of the upstream area. An example would be the jumping of salmon at an obstruction. There may also be inadequate numbers of fish to spread spawners upstream. In these cases, transplantation of stocks may be necessary to speed up the colonization process, and achieve some use of the newly-accessible area within one to two population cycles. The best adapted sources of stock are likely to be either the existing population below the obstruction, or secondarily, the population from a nearby stream.

There are many obstructions to migration which are too formidable to remove or alleviate. However, the areas above these obstructions may still be utilized by rearing species such as steelhead and coho through annual transplants of eggs or fry.

Because transfers of fish stocks between streams could cause fish diseases or harmful interactions between the introduced species and species already present, *all transplant proposals must be reviewed and approved by the Interagency Committee on Transplants, which includes representation from the federal and provincial fisheries agencies.*

Salmonid stocks may be transplanted at several stages in their life cycle: as mature adults, as either *green* (newly-fertilized) or eyed eggs, as fry, or as more advanced juveniles, at any stage up to seaward migration. Transplants may require rather sophisticated approaches to capturing and transporting stock, as well as considerable knowledge of fish culture. A thorough treatment of these subjects is available in specialized technical publications such as those cited in Appendix A. This guide reviews the general approaches and requirements, to provide the reader with an appreciation of the subject.

Adult Collection and Holding

Maturing adult salmonids may be collected in several ways: by angling, by traps in fishways or counting fences, by beach seining or by a short length of drifted gillnet (Fig. 11.26). Captured fish are usually transferred to floating pens in the stream or to ponds, for holding until they are ready to spawn (Fig. 11.27). Depending on the maturity of the fish, this holding period may range from several days to several months. An experienced fish culturist

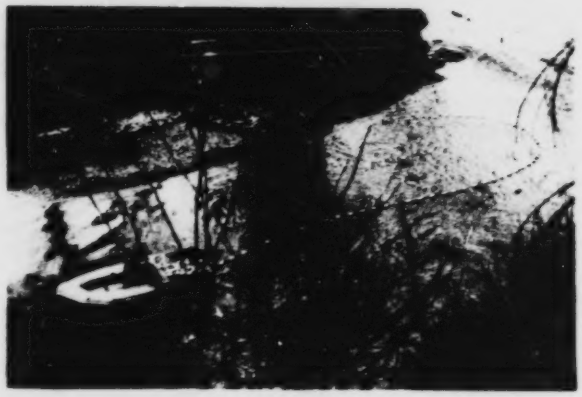


Figure 11.26 Setting a beach seine for adult salmon in a small river to obtain eggs for a transplant.

Figure 11.27 Sockeye salmon held to maturity in a pen for subsequent spawning and egg transplant to a barren stream.

should be consulted on the design of fish holding areas, particularly in the case of stocks such as summer-run steelhead and chinook which must be held for long periods.

As adult salmonids approach sexual maturity, they become less susceptible to injury from capture, easier to handle, and more likely to survive a period of confinement. Where possible then, adult collections should be conducted at a stage close to spawning to minimize the holding period. However, when a stock with a particular run timing characteristic is sought, it may be necessary to collect adults on their upstream migration because fish captured at a later stage on the spawning grounds may be an indistinguishable mixture of early- and late-run stocks.

Transfers of Adults

Mature adult salmonids can be transferred directly upon capture to the area of stream above an obstruction. This method of initiating the colonization of an area has been used successfully, however, there have also been instances where some of the transferred stock has dropped back downstream to spawn in the area from which they were captured.

A large-volume transport tank with an air or oxygen supply is required for transporting adult salmonids any appreciable distance. In some cases, salmon have also been transported by helicopter, either to populate barren areas or to provide emergency transport around a landslide blocking upstream migration (Fig. 11.3).

Transfers of Eggs and Fry

For small-scale projects, it has been more common to transplant stocks to the stream or area of release at either the egg or fry stage. Transfers of fertilized eggs must be carried out within 24 hours of spawning (Fig. 11.28), while the eggs are relatively insensitive to shock. Fertilized eggs should be allowed to *water harden* for ½ hour before being transported. The transplanted eggs are normally placed in an incubation facility located on the barren stream system into which the fry will be stocked.

Alternatively, the eggs may be incubated either at the donor stream or at a third site, with the transfer between streams taking place at the fry stage. This second approach is most likely to be used for species such as coho salmon and steelhead trout, which have a stream-rearing phase in the life cycle. On emergence from the gravel the fry of these species should be distributed throughout the stream, to ensure that they fully utilize the area available for rearing.

Considerable numbers of coho salmon fry can be found in side channels or pools which will eventually become isolated from the main stream or dry up during the summer low flow period. As most of these fry would probably not survive the summer, they are a good source of stock for transplants to suitable stream areas above obstructions. They can be collected with a small beach seine and transferred in portable, water-tight containers. To prevent overloading and possible mortalities enroute, consideration must be given to the number and weight of fish per

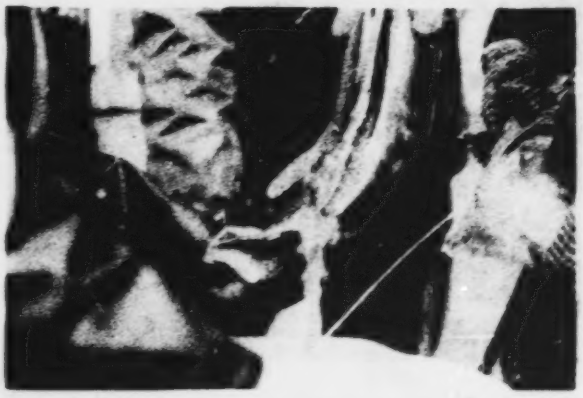


Figure 11.28 Artificial spawning and fertilization of salmon eggs.

container, and the possible need for a supplementary air or oxygen supply. The time required for each trip, the water temperature and likely rise in temperature during transport must be taken into account. Trials with small numbers of fry can be used to indicate the appropriate fish-loading density.

Streamside Incubators

Several types of streamside incubator have been developed. Each consists essentially of a box, in which eggs are placed between layers of graded gravel (Fig. 11.29). Water is piped to the box and introduced at the bottom, in a manner which produces an evenly-distributed upwelling flow pattern. Gravel has been found to be essential for producing fry which are comparable in size and emergence timing to those incubated under natural conditions. When their yolk sacs are fully absorbed, the fry emerge at night from the gravel and swim via the surface outlet to a screened live-box. The fry are then ready to be either released, transferred to another location, or reared for release at a later stage.

The simple plywood incubator shown in Figure 11.30 can carry in the order of 50,000 salmon eggs. It requires a water flow of only 50 litres per minute, or 1 litre/min per 1,000 eggs. If the water supply is relatively free of silt, an egg-to-fry survival rate of 70 to 90% can be expected. A filter or silt-settling basin should be located between the intake and the incubation box. In cold climates, it may also be necessary to place styrofoam insulation around the outside of the indubator, to prevent freezing. Copper, brass and galvanized metals are highly toxic to salmonids and should not be used in either the incubation box or the associated piping.

A plexiglas window may be incorporated in one side of the incubation box to enable periodic observation of embryo development and egg survival. As continuous exposure to light could be harmful to the developing embryos, the window must be covered with a light-proof material.

Figure 11.29 *Placing fertilized salmon eggs in the gravel of a streamside incubation box. The eggs must be planted within hours of fertilization, before they become sensitive to handling and shock.*

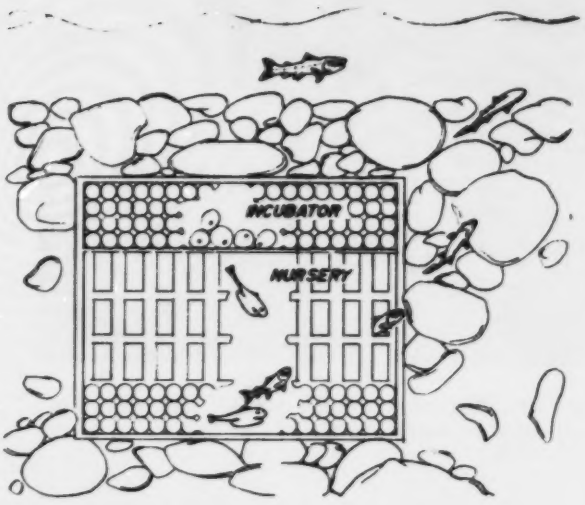


Figure 11.31 *The Whitlock-Vibert Box, used for egg plants in the stream gravel. Eggs are placed in the upper compartment. On hatching, alevins drop through to the lower compartment, where they remain until their yolk sacs have been absorbed. This technique has not been evaluated under British Columbia conditions.*

Incubators can also be constructed out of fibreglass or aluminum, and can be round, square or rectangular. However, the most important consideration in establishing an incubation facility is to ensure that the water supply is reliable, free of silt and debris, and that the temperature regime is suitable. Salmonid populations are adapted to the incubation temperature regime of their native stream. In the case of egg transplants, a water supply warmer than that of the donor stream will cause an abnormally high rate of embryonic development and premature emergence of fry, before the normal spring increase in food supply and at a temperature much below optimum for growth. In addition, an abnormally cold temperature regime can cause mortality of eggs during the early stages of development, before the eyed stage is reached. Silt causes egg mortality by clogging the gravel and reducing the supply of oxygen to the egg, and also by adhering to the surface of the egg, thereby interfering with oxygen exchange across the egg membrane.

Under relatively high incubation temperatures the growth and spread of fungus from dead eggs to live eggs may increase egg mortality significantly. The daily addition of a malachite green solution up to several times per week can effectively control fungus. As this solution is lethal to alevins and fry, it must only be used on eggs. A fish culture manual should be consulted for procedures.

Planting of Eggs

Salmonid eggs can be planted at either the green or eyed stages directly into artificial *redds* excavated by shovel in the stream gravel. The preferred location is the upper part of a riffle, similar to known spawning areas. A cylin-

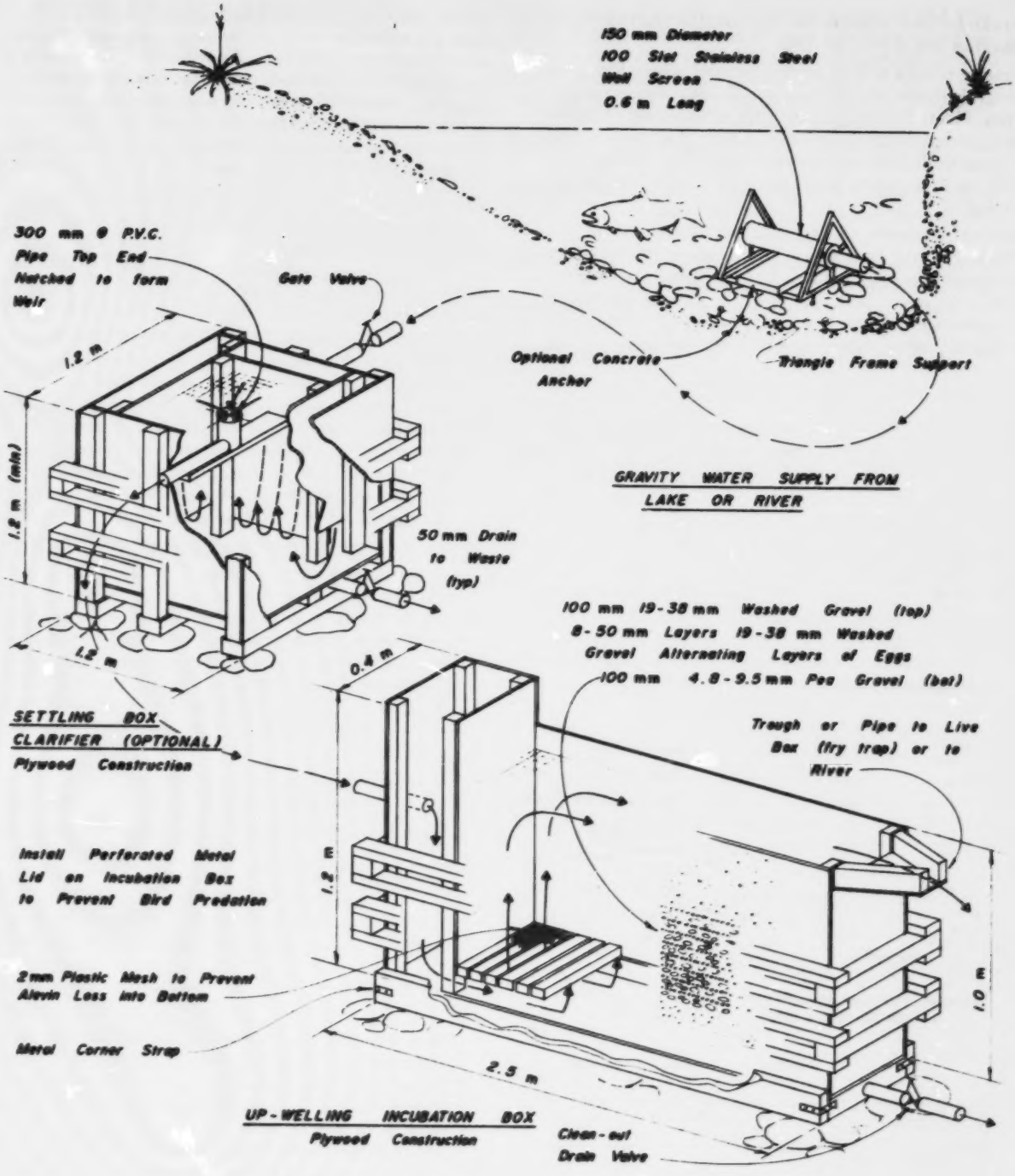


Figure 11.30 *50,000 Egg Upwelling Incubation Facility. The settling box clarifier is not required for lake installations. Incubation and settling boxes should be insulated in cold climates. Fiberglass and aluminum can be used as alternate construction materials.*

der can be used to guide the eggs into the gravel if water velocities and depths are high.

Planting of eggs will be most successful where flows are relatively stable, and a supply of suitable spawning gravel exists. Plants of eyed eggs in artificial spawning channels have produced egg-to-fry survival rates of up to 90%, but in uncontrolled natural streams the method can not generally be expected to result in survivals of more than 30 percent.

Another approach to egg planting is the use of the Whitlock-Vibert box, which affords some protection to the developing eggs and alevins from either predators or shifts in the gravel beds. About 200 to 300 eggs are placed in a translucent plastic box measuring 15 x 9 x 6 cm, with slots which allow a good flow of water and enable fry to escape when they are ready to emerge (Fig. 11.31). Eyed eggs are normally used, as this allows removal of dead, unfertilized eggs and thus reduces the likelihood of a fungus problem. The box is buried in excavated gravel to a depth of 10 to 20 cm. An anchor is attached to prevent the box from being scoured from the stream bed. The approximate survival can be determined by examining the box for dead eggs after fry emergence.

The Whitlock-Vibert box is a relatively trouble-free method, not vulnerable to vandalism which could affect an incubation box operation. However, ***this method has not been adequately tested and assessed under a variety of British Columbia conditions.*** As with any egg planting method, it would not be suitable in stream reaches with high quantities of suspended or bedload sediments.

12. STREAM CHANNEL IMPROVEMENTS

Physical conditions within stream channels can be modified to improve or increase particular habitat for salmonids. However, *if such modifications of the channel are to heve any degree of permanence and success, they must incorporate the principles of stream hydraulics*. The end result will also depend on correct identificaton of the factors limiting freshwater production of the species in question. For example, there would be no benefit from increasing spawning area for a coho salmon or steelhead trout population if the stream's juvenile rearing capacity were the factor actually restricting production.

In British Columbia, experience in stream channel improvement for salmonids has been somewhat limited. The most common activities have been log jam and debris removal, restoration of obstructed side channels, and measures to stabilize unstable reaches of streams affected by floods. However, several channel improvement concepts developed for eastern North American conditions are currently being evaluated and adapted to suit the more rugged environment of coastal British Columbia.

Physical Processes in Streams

The two principal forces acting on water in a stream channel are gravity and friction. Gravity causes water to move downstream, while friction between water and the stream bed and banks resists this downstream movement. The velocity of the water depends not only on slope and roughness of the streambed, but also on the depth of flow. A large, deep river with the same gradient as a small, shallow stream will normally have a much greater velocity.

Resistance to flow, in either natural or man-made water courses, is influenced by the following factors:

- size of material which makes up the bottom and banks of the stream;
- amount and type of vegetation along the stream banks, including vegetation within the wetted area;
- degree of curvature and the frequency of pools and rapids, all of which affect the uniformity of the stream bottom; and
- obstructions to flow, such as rock outcrops and log jams.

As water velocity increases, these factors provide progressively more resistance to the flow. This causes eddying, local reverses in flow, hydraulic jumps, chutes and waterfalls, which may dislodge and move the resisting object downstream. Resistance to flow tends to increase as the square of the velocity, a factor which applies to all turbulent flow conditions. For example, as the flow doubles the drag forces on an object will increase by a factor of four. In this regard, it is the peak or dominant discharge that governs the physical processes in streams.

To appreciate the capabilities and limitations of a particular stream enhancement technique, one should have a fundamental knowledge of the factors described above, as well as an understanding of stream geometry and flow. Natural streams are seldom straight over a distance greater than 10 channel widths. Three general terms are used to define the basic types of stream forms:

Straight — applies mainly to *relatively straight* or *non-meandering channels*.

Braided — channels which successively meet and redivide.

Meandering — single channels with a high degree of sinuosity or an *S-shaped* channel pattern.

The sinuosity of a meandering channel is defined as the ratio of the distance measured along the centreline of the channel to the distance measured in a straight line across the bends (Fig. 12.1). Streams with sinuosities of 1.5 or more are classed as *meandering*, those below 1.5 are classed as *straight*.

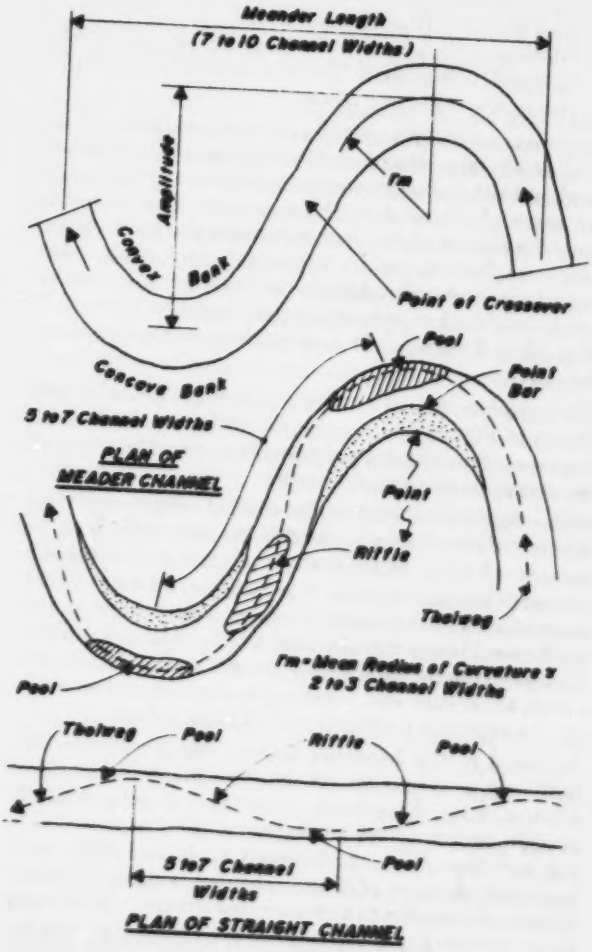


Figure 12.1 Elements of various channel forms and their physical relationships.

A stream will always attempt to maintain a meander shape, as this is the type of curve involving the least work in turning and therefore the most likely path for water to follow. Even where the channel appears straight, the line of maximum depth, called the *thalweg*, wanders back and forth across the channel in a meandering pattern (Fig. 12.1). Where obstructions to flow cause a stream to depart from this normal meander shape, the stream will always tend to restore this natural configuration.

In view of the importance of the meander configuration and the *thalweg* concept to stream enhancement work, a few general *rules of thumb* governing meander shape have been summarized below and illustrated in Fig. 12.1.

(1) Channel width, meander length and radius of curvature are closely related.
(2) Meander length ranges from 7 to 10 times channel width as measured in a straight line. When measured along the centreline of the channel, the length between identical points on the meander waves varies from 10 to 16 times channel width.
(3) Successive crossovers (2 per meander) are spaced 5 to 7 channel widths apart. This is similar to the spacing of successive riffles in a stream.

Two cross sections of a meander channel are shown in Fig. 12.2. One is taken at a point downstream of the axis of the bend and shows the transverse spiral flow developed at the curve of a meander. The transverse flow proceeds along the bottom of the channel towards the inside of the curve and then on towards the outside bank. This transverse flow at a bend results in bedload deposition at the point of a meander, and subsequent creation of a point bar (Fig. 12.1). Floating debris accumulates on the outside of the curve.

The tranverse flow in a straight section of channel is also shown in Fig. 12.2. In a straight section of channel the transverse flow converges at the surface near the center of the stream as two spiralling cells.

These flow characteristics for straight and meandering sections of a stream are some of the important factors to be considered when locating water intakes or carrying out stream enhancement work. For example, if a water intake were located on the inside or convex bank of a curve, the intake would be eventually buried by bedload deposition. Conversely, if the intake were located on the outside of a curve, a trashrack and screening system would be necessary to minimize problems with floating debris.

As noted in the following section, the pool and riffle regime in a river is one of the most important physical influences on the natural production of salmonids. A straight, non-meandering channel usually has an undulating bed that alternates between pools and riffles at a repeating distance of 5 to 7 channel widths. This frequency also applies to a meandering stream, where pools occur at every curve and riffles at each point of crossover. This alternating pool and riffle sequence, present in practically all channels having bed material larger than coarse sand, is characteristic of most salmonid streams in British Columbia.

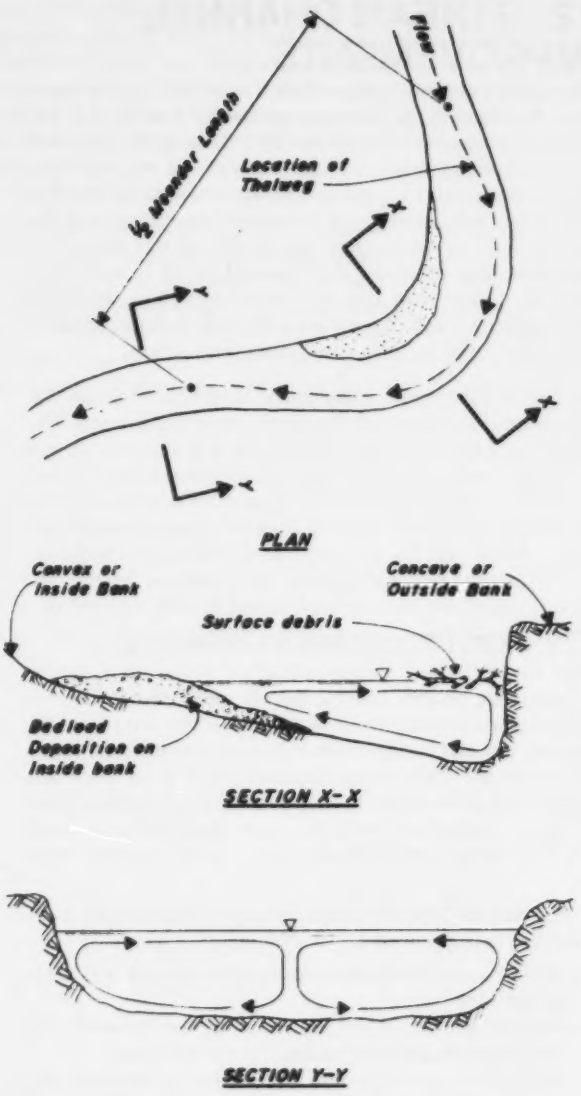


Figure 12.2 *Section X – X – Transverse flow at the bend of a meander. Surface water and debris spiral toward the outer bank, bottom water and bedload spiral toward the inside bank.*

Section Y – Y – Transverse flow in a relatively straight channel. Spiralling flow converges at the surface near the centre of the stream.

In addition to the physical characteristics of the stream channel, erosion and movement of sediments should also be considered when manipulating a stream to enhance salmonid production. Channel shape and cross-section will vary considerably, depending on the characteristics of the bank material. When stream banks become more resistant to erosion, because of the size and gradation of

Table 4. Transport velocities for various classes of streambed materials.

Material	Diameter	Transport Velocity
Silt	0.005 - 0.05 mm (0.00002 - 0.002 in.)	15 - 20 cm/sec (0.49 - 0.66 ft/sec)
Fine to Coarse Sand	0.25 - 2.5 mm (0.01 - 0.10 in.)	30 - 65 cm/sec (0.98 - 2.13 ft/sec)
Fine to Coarse Gravel	5.0 - 15 mm (0.2 to 0.6 in.)	80 - 120 cm/sec (2.62 - 3.94 ft/sec)
Fine to Coarse Stone	25 - 75 mm (1.0 - 3.0 in.)	140 - 240 cm/sec (4.59 - 7.87 ft/sec)
Cobbles	100 - 200 mm (4.0 - 7.8 in.)	270 - 390 cm/sec (8.86 - 12.80 ft/sec)

the natural bank material or due to reinforcement by man, the hydraulic forces of the stream will scour a deeper channel. In general, the shape of the the cross-section of a stream channel is determined by the discharge and the characteristics of the materials that make up the bed and banks of the channel, as well as the type of vegetation within and adjacent to the channel.

As discharge increases in a stream channel, not only does the water level rise at a specific point, but the streambed may be lowered due to scour. For gravel streambeds, the scour depth may be only minor. However, in streams with sandy bottoms the streambed scour will be much greater relative to the rise in water surface level. Streambeds with sandy bottoms will often scour to a depth of about one third the overall rise in water level. This factor is very important when carrying out stream enhancement work, particularly in stream channels formed in silt, sand or other fine materials. Rock weirs and bank revetments, gabion wing dams and other structures described in later sections of this manual, will be unstable if located on sandy stream bottoms. There will be a tendency for structures to be undermined, resulting in the lowering, breakup and downstream movement of the various components of the installation.

Also, pools which are incorrectly located will fill with bedload material. Structures such as diversion weirs, screening facilities, sumps and other portions of facilities within the stream may become buried or partially filled as a result of bedload deposition. In British Columbia, bedload deposition commonly causes either complete loss or reduced performance of an instream structure.

Streams subject to large freshets or fluctuations in water levels will have higher rates of erosion and greater sediment transport. The basic premise that a particle requires considerably more force to initiate its movement than to keep it in motion is evident in any stream with widely fluctuating flows. The extreme peak flows initiate particle movement, while the lower flows have sufficient carrying power (transport velocity) to keep the particle moving.

Uniformity of particle size is also a key factor in bedload movement. For two samples of bed material with the same average size of particle, the sample with less uniform particle size will be more stable, because the smaller particles will fill the voids and thus lock the larger grains in place. Summarized in Table 4 are the minimum transport velocities for various sizes of particles.

Table 4 can also be used to estimate the velocities that usually occur in a river channel, simply by inspecting the river bed materials. If the channel consists of cobbles with very little gravel or sand, the stream regularly has velocities in excess of 200 to 800 cm/sec (8-10 ft/sec). Alternatively, if the maximum velocity of a specific section of channel is known, a rough estimate of the size of bed material that will be relatively stable in that section can be determined. This is particularly important where gravel or cobbles are being added to a stream channel to improve spawning conditions or to modify stream characteristics.

The average velocity for any given length of channel can be readily estimated by placing a small, nearly submerged float in midstream and timing its passage over a measured distance. This will give a slightly high estimate of average velocity. One can then estimate stream discharge or flow by multiplying the average velocity by the wetted width of the stream times the average depth.

The foregoing information on bedload transport velocities and approximate methods for determining river flow and velocity can be used to make a cursory assessment of any section of channel prior to carrying out stream enhancement work.

Also, stream improvement structures should be planned and designed so they do not create the undesirable hydraulic conditions discussed in the section on obstructions to adult migration (Section 11). A man-made weir and pool installation often works well for one season, but as sand and gravel from upstream fill in the pool area, a hydraulic jump may form and create an undesirable situation for fish.

Improvement of Rearing Habitat

Juvenile salmonids that rear in the stream require physical habitat which satisfies three basic requirements: (1) a feeding location with suitable water velocity, near a

***Figure 12.3** An example of differences in summer habitat preferences of juvenile salmonids, related to species and life stage. One year old steelhead parr (Sp) occupy bouldery fastwater locations at head of the pool. Coho fry (C) seek deeper, slower areas of the pool close to bank cover, and steelhead trout fry (Sf) are found in the shallower tail of the pool where the water accelerates into a riffle.*

strong current carrying an abundance of drifting insect food; (2) concealment from predators and competitors; and (3) a sanctuary from extremes of flow and ice formation. As they grow, juvenile salmonids seek progressively higher water velocities, often shifting from areas near the stream margin to midstream locations. The advantage of this behaviour is thought to be an increase in access to insect drift food. During winter, all species tend to seek areas of lower water velocity. Presumably this favours conservation of energy reserves during a period of poor growing conditions, and also enables the animal to cope with winter extremes such as ice and floods.

Though their basic requirements are the same, the species differ in the type of habitat they utilize. Even within a single species, habitat preferences change as the fish grow. Fig. 12.3 depicts these differences in habitat preference for coho salmon and two age groups of steelhead trout.

Habitat Requirements

Juvenile coho salmon tend to rear in pool areas of moderate velocity (less than 30 cm/sec) during the summer. The preferred habitat is a pool or backeddy in association with an undercut bank, submerged tree roots, branches or logs. In winter, coho shift to slower and deeper pools, or to side channels and pools off the main stream. At this stage of relative inactivity, they seek cover under rocks, tree roots, logs, debris, and in log jams.

The habitat requirements of juvenile steelhead trout must be considered in both their first year of life, as underyearlings or fry, and in the second and subsequent years of rearing, at the parr stage. During their first summer the underyearling steelhead are generally found in relatively shallow areas, over a cobble or boulder bottom at the tail of a pool, or in a riffle less than about 60 cm deep. In winter, they hide under large boulders in shallow riffle areas. Preferred summer habitat of steelhead parr includes stable log jams, heads of pools, runs, and riffles. Large boulder substrate is important in runs and riffles. Surface turbulence or white water is an important feature of the overhead cover in these areas. During winter, steelhead parr are found in pools, under debris, logs and boulders, usually associated with bank cover.

Cutthroat trout generally inhabit streams with lower gradient than those which support steelhead. However, the habitat requirements of juvenile cutthroat appear to be generally similar to those of steelhead.

Dolly Varden fry and parr are found in the same general type of habitat, ie. riffles and runs, as juvenile steelhead.

Chinook salmon juveniles rear in relatively large streams. During the early stages of stream life, their habitat requirements appear to be similiar to those of coho salmon. Immediately after emergence as fry, they are found along the stream bank, close to cover such as undercut tree roots or logs. As the young chinook salmon grow, they tend to move into locations of higher velocity either along the stream margin or in bouldery runs away from the shore.

For species such as steelhead and cutthroat trout, which generally reside in the stream for two or more years before migrating out to sea, stream improvement efforts should focus on creating or improving both summer and winter habitat for parr. It is at this life stage that the available habitat will most likely limit smolt production.

General Guidelines

Enhancement techniques to improve rearing habitat must be applied with care, because poorly planned work may cause damage to the natural stream. The following

general guidelines must be considered before modifying existing features of the stream.

(1) Pool and riffle areas repeat at approximately 5 to 7 channel widths, regardless of whether the stream has a meandering or straight configuration. This natural stream form must be maintained, and the addition of any devices to improve the rearing habitat must compliment the natural stream configuration.

(2) Devices in streams must be located to avoid backflooding the section immediately upstream. Riffles can be flooded out and pools can be reduced to a velocity which is no longer acceptable to rearing salmonids. In general, stream devices should guide the current rather than dam the flow.

(3) All stream devices must be constructed in low profile to permit free passage of drifting logs and debris.

(4) All structures should be built solidly, and of sufficient size to withstand the normal flood flows. They must also be effective during low flow conditions.

(5) Construction materials should be natural, wherever possible, should be durable enough to withstand freeze-thaw cycles and hydraulic forces, and must be reasonably resistant to decay.

(6) Devices to improve a specific section of stream must be installed in a manner which will not damage adjacent areas of high value to fish. When heavy equipment is used, it is especially important to avoid traversing good, stable areas of natural stream to reach the section being improved. To destroy 50 metres of stream in order to enhance 10 metres is obviously not prudent.

(7) All stream work, particularly where heavy equipment is involved, must be timed to avoid conflict with the spawning and incubation periods of the various salmonid species.

(8) Stream banks must be well protected (reveted) if a stream device accelerates the flow or turns the flow toward a bank. This is particularly important where there is a possibility of damaging existing fish habitat or private property.

In the following sections, various types of stream devices for enhancing salmonid rearing habitat are described. However, the general guidelines noted above must be kept in mind when locating and constructing the various installations.

Creating Pools or Runs

Wing-deflectors are a common device for modifying or improving stream channels. They are installed along the upstream edge of a point bar as an erosion-resistant leading edge. A well-constructed system of wing deflectors, alternating from one side to the other, will maintain the normal meander pattern (Fig. 12.4). Due to the resultant concentrations of flow, pools at bends will become deeper, the banks will undercut more, and the resulting sands and silts will be deposited at the downstream end of the wing deflectors as point bars (Figs. 12.1 and 12.5).

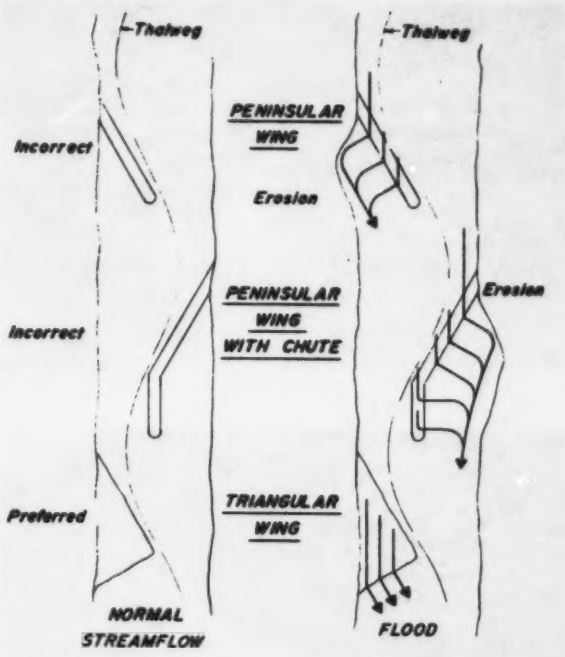


Figure 12.4 Performance of various kinds of wing deflectors under normal stream-flow and flood conditions. Water course is straightened to simplify the diagram (Adapted from White and Brynildson, 1967).

A few general *rules* must be considered when installing a wing deflector to create pools and runs:

(1) Avoid installations in unstable floodplain or braided channel reaches of stream. In these areas structures may rapidly become ineffective or may add to existing instability.

(2) Locate the deflector well down the riffle to avoid impounding water upstream.

(3) Deflectors should form an angle with the stream bank of 45 degrees or less. Experience indicates that this improves their performance. The appropriate angle and length of wing will be specific to each site, and should generally conform to the natural meander sequence of the stream.

(4) Boulders and/or rock-filled gabions are best suited for construction of wing deflectors. When individual rocks are used, the size of individual boulders will depend on the characteristics of the stream. Generally, rocks for wing deflector construction should not be less than 0.6 m in diameter.

(5) Where the wing deflector connects to the river bank, the point of connection *must be protected by rip-rap or gabions* to above the flood level, so as to prevent the river from washing around the end of the deflector (Fig. 12.6). Similarly, the bank opposite the deflector must also be protected to eliminate erosion

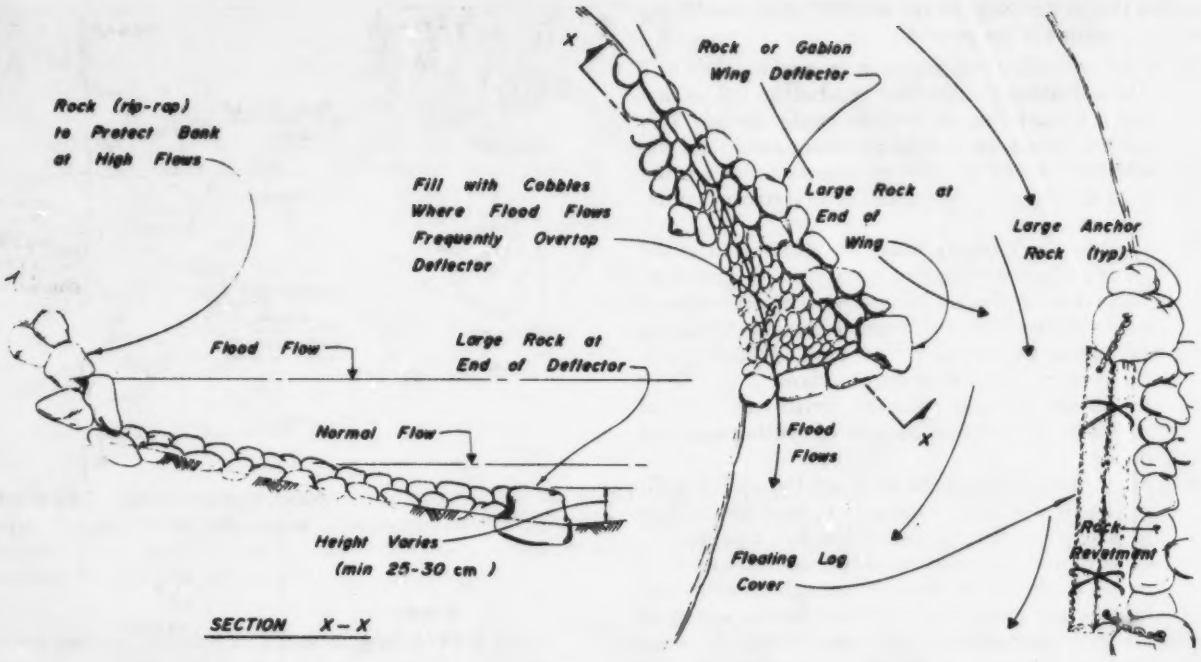


Figure 12.5 *Typical wing deflector constructed from rock. The current will scour a deeper pool on the opposite bank. Two logs lashed together with cable provide floating cover. Anchor cable must be located to avoid snagging debris.*

that could be harmful to fish habitat or streamside property.

(6) To minimize scour of the foundations of wing deflectors constructed with large rock, always use a minimum of two rows of rock, with the joints staggered. The second row should be set into the bottom of the river with the top slightly lower than the first row of rock, and the deflector should be triangular in shape (Fig. 12.5).

(7) If possible, securely cable log cover (preferably cedar) to the revetment on the opposite bank to provide additional cover and accelerate scour of the pool or run.

(8) Where the stream bottom is composed of coarse material, pre-excavation of the intended pool or run will be required to speed up the natural erosion process and to ensure development of suitable habitat.

(9) The height of the wing deflector should be set so that at peak flows it is sufficiently submerged to pass logs and debris. If the deflector is set too high, severe bank and channel erosion could result.

Other devices have been used to form and maintain small pools or *pockets* in a stream channel. In British Columbia, grouping of boulders have been found to be the most effective method of increasing rearing habitat for juvenile coho and steelhead. These installations consist of carefully placed boulders generally located at the upstream end of a very shallow pool or run area, and favouring the outside of a curve. Other effective locations are at the middle and downstream portions of a riffle.

Three to five large, well-placed boulders, normally 0.6 to 1 m in size for most small streams, will create a stable run area within the riffle as well as provide cover for rearing salmonids (Fig. 12.7). In large streams, boulder groupings can be repeated in a staggered arrangement down the length of a riffle, thus maximizing fish production. If correctly placed, the combined action of turbulent flow around the boulders and the transverse flow which develops on a bend will minimize bedload depositon downstream of the rock grouping. In some locations a short wing deflector may be required in conjunction with the rock grouping to prevent gradual deposition of bedload material around the individual boulders. Suitable rock is often available from quarries operated by forest and mining companies. Large boulders can also be obtained at the base of talus slopes.

These rock grouping installations require minimal maintenance because minor movements of individual rocks do not seriously reduce the installation's effectiveness. However a suitable spacing (2-3 m) must be maintained between the individual rocks to avoid accumulating debris and trapping bedload material. Where the stream substrate is coarse, some pre-excavation may be necessary to ensure a *pocket* forms adjacent to the individual boulders. This is particularly important for obtaining utilization by coho salmon, but it appears that it may

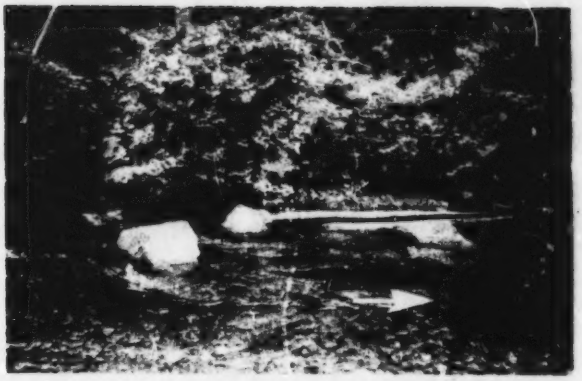
Figure 12.6 Gabion wing deflector (upper) The gabion revetment on the far bank should have been carried further downstream to prevent uncontrolled scour, which could render the device ineffective.

Boulder wing deflector with floating log cover(lower). At high flows water will be diverted around the bank-end of the deflector, thus reducing the efficiency of an otherwise good stream device. Cabled log cover attached to the boulder revetment improves habitat for larger fish such as steelhead parr.

not be essential for steelhead juveniles.

Helicopters have also been used successfully to place boulders in reaches of the stream that are inaccessible to land-based construction equipment. Damage to stream banks and fish cover can be avoided entirely, and in many cases the stream area available for enhancement may be substantially increased. Direct costs of helicopter installation can be comparable to those incurred with conventional equipment.

Another pool-forming device, the *Hewitt Ramp*, should only be employed in small, high gradient streams. This device is essentially an inclined ramp with a plunge pool at the downstream edge. The Hewitt Ramp must be located so as to minimize ponding and consequent deposition of sand, silt and bedload upstream of the ramp. This



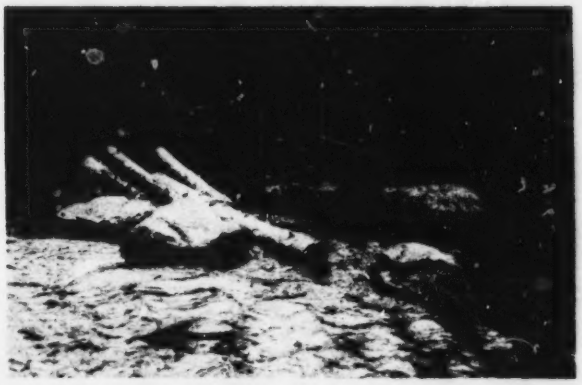


Figure 12.7 Boulder groupings with floating log cover, located on the outside of a stream bend. This is one of the most productive improvement devices for juvenile coho and steelhead. The upstream ends of the logs should be securely cabled to the downstream face of the largest boulder.

device uses the principle that water falling freely over a ledge tends to surge back and scour beneath the ledge. Though the Hewitt Ramp permits this hydraulic action, it is constructed to prevent excessive undermining and collapse. The plunge pool formed is self-scouring and provides ideal conditions for fish to leap the obstacle.

The Hewitt Ramp is usually constructed on a relatively stable, steep gradient stream with a firm channel bottom (Fig. 12.8). It is usually made of logs and timber. The log forming the ramp crest must be securely anchored into the banks on both sides of the stream and ballasted with rock. Since logs and timber have a limited life, particularly when portions of the structure are not continuously submerged, an alternate ramp constructed of selected rock shapes can be used (Fig. 12.9). With this type of ramp, it is important to ensure that the rocks forming the downstream weir are oblong in shape, to maintain stability even when one third of the rock is undermined. Often abandoned rock quarries have selected pieces of rock ideally suited for this application.

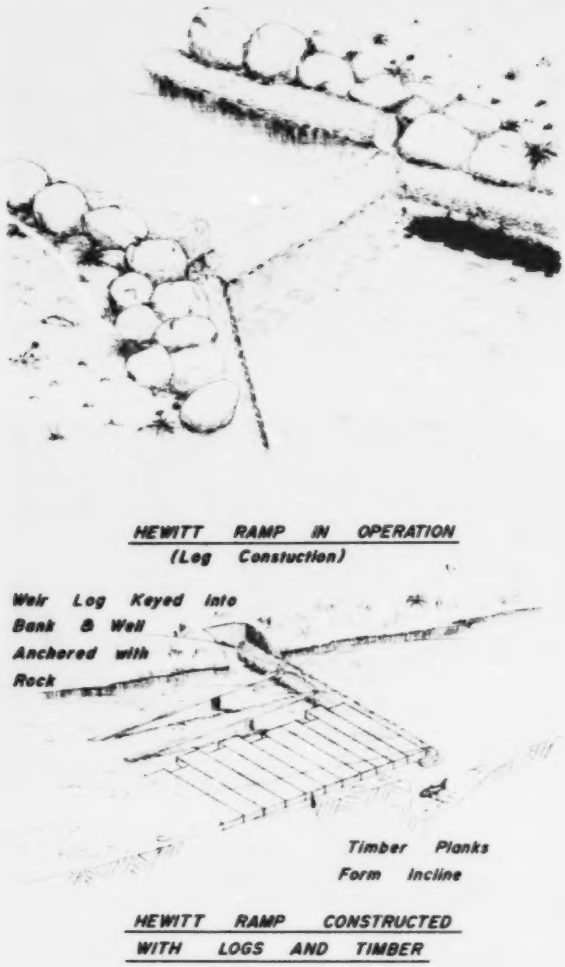


Figure 12.8 *Hewitt Ramp constructed of logs and timber. Undercut plunge pool forms downstream and is readily passable by both upstream and downstream migrants. This device must only be used in small, high gradient streams to avoid deposition of silt and debris upstream.*

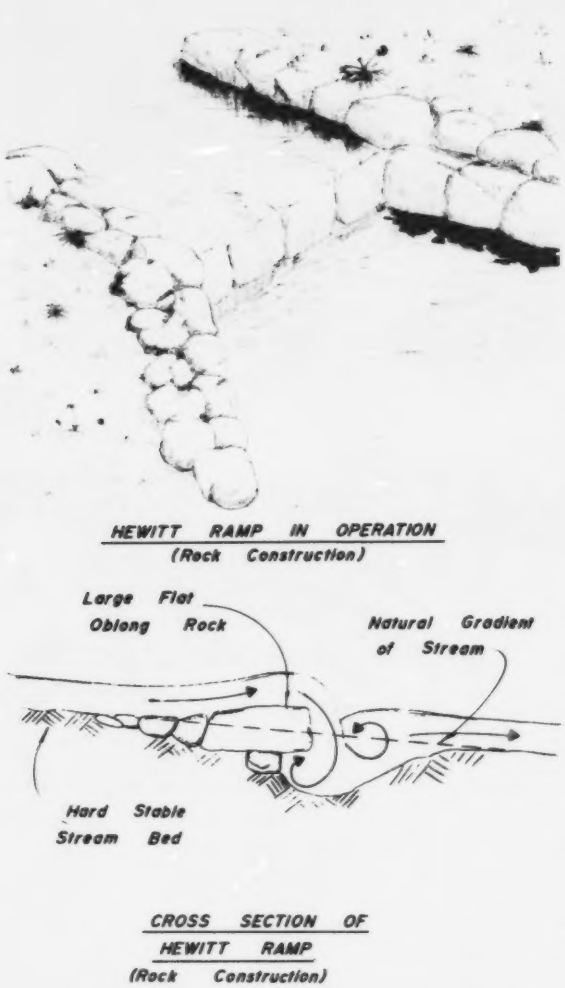


Figure 12.9 *Modified Hewitt Ramp utilizing selected natural stone or quarry rock. Large, flat, oblong rocks form weir crest to permit undermining caused by plunge pool. This device must only be used on small, high gradient streams.*

The Hewitt Ramp has limited application in British Columbia. It should only be used in small, relatively stable streams with a steep gradient. This device would generally be best suited to streams in the interior of the province. Figure 12.10 shows a submerged weir located at the upstream end of a meander, where a pool or run is too shallow. Due to the angle of the weir with the stream and the dipping cross-slope, the flow is concentrated against the outside bank of the curve, increasing the amount of erosion and forming a longer, deeper self-cleaning pool. Since the weir is normally submerged, logs can be used with good life expectancy. Stone-filled gabions and selected pieces of quarry rock can also be used to construct a submerged weir. In areas where rock is difficult to find, rejected pieces of concrete highway divider curb can be used. Because this device is submerged and only a small portion of the top of the weir will be visible through the water, the precast concrete sections will not detract appreciably from the natural aesthetics of the stream.

Other devices have been used to develop pools within a stream, but some of them tend to create problems. For example, while pools may form below a low log or timber dam, silt and debris often deposit upstream of the dam,

blanketing and destroying riffle areas which are important for spawning and aquatic insect production. In addition, timber and logs exposed to both air and water soon decay to a process known as *dry rot*. The term dry rot is a misnomer, because the decay is caused by a fungus growing in moist wood. When exposed to air, the fungus soon reduces a wood structure to a soft pulp. Green woods used in any of the applications described in this guide would be more susceptible to dry rot than seasoned wood. In coastal British Columbia, cedar is the most durable wood and is recommended for use in streams.

Another type of device used to create pools is a *digger* log. It consists of a floating log anchored to the stream banks at right angles to the flow (Fig. 12.11). The action of the current against the log forms a depression or pool below it. Though these devices work satisfactorily in controlled streams, they are not recommended for natural streams, as the log will trap floating logs, roots and debris, eventually damming the channel.

V-deflectors and mid-channel or A-deflectors have also been used to scour pools (Fig. 12.11). In the case of A-deflectors, the narrow passages located on each bank will often clog and widen the stream, or the stream flow will be diverted around and over the bank protection. Similarly, V-deflectors (also known as V-notch weirs) can also plug and dam the stream, causing bedload deposition and flooding around the rip-rap abutments. Though they can be effective in creating rearing area for salmonids, these deflectors are relatively expensive to construct and tend to break down rapidly if the boulders are undersized.

The beds of some streams in British Columbia are formed entirely in bedrock. Some success has been achieved by blasting pools in the bedrock to form *pockets* for rearing salmonids. The location of the pool must be selected so as to use stream velocities to avoid deposition of bedload. In addition, the pool must be constructed and located to avoid undesirable hydraulic conditions such as the creation of a swirling vortex or high velocity flow in which fish are unable to rear.

In the sedimentary bedrock deposits of interior British Columbia the alternating layers of soft and hard rocks can be utilized to create fish habitat by initially excavating the soft rock layer and then concentrating the flow to promote further erosion. The harder rock layers would then form the erosion resistent edge or boundary of the improved stream section.

A good rule to follow when creating pools in a rock section of stream is to *improve and enlarge* existing natural areas of pool development, rather than attempt to create an entirely new pool area which may conflict with the natural stream processes.

Rock Revetments

Rock or rip-rap revetments are a simple method of protecting stream banks from erosion. The outside curve of a meander can be protected with broken rock, to minimize bank erosion and improve fish cover. This often results in deepening of natural pools by increased bottom scour.

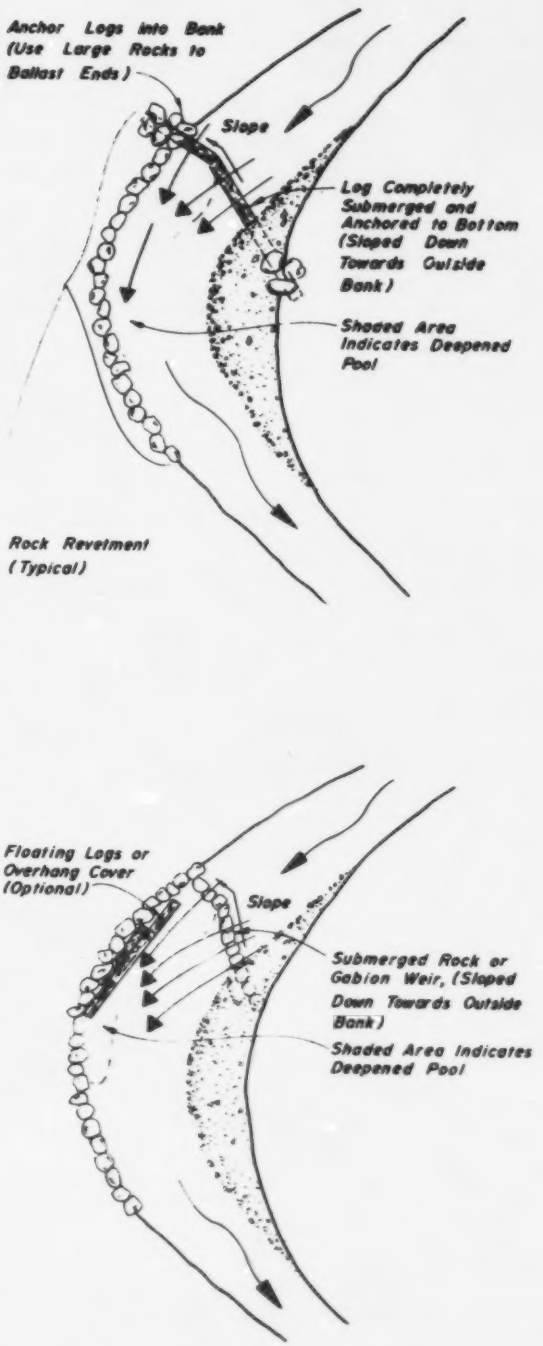

Anchor Logs into Bank (Use Large Rocks to Ballast Ends)
Slope
Log Completely Submerged and Anchored to Bottom (Sloped Down Towards Outside Bank)
Shaded Area Indicates Deepened Pool
Rock Revetment (Typical)
Floating Logs or Overhang Cover (Optional)
Slope
Submerged Rock or Gabion Weir, (Sloped Down Towards Outside Bank)
Shaded Area Indicates Deepened Pool

Figure 12.10 Submerged inclined weirs, when located upstream of a curve, create larger and deeper pools. Logs, rocks, gabions and concrete highway curbs are common materials used for constructon (Adapted from White and Brynildson, 1967).

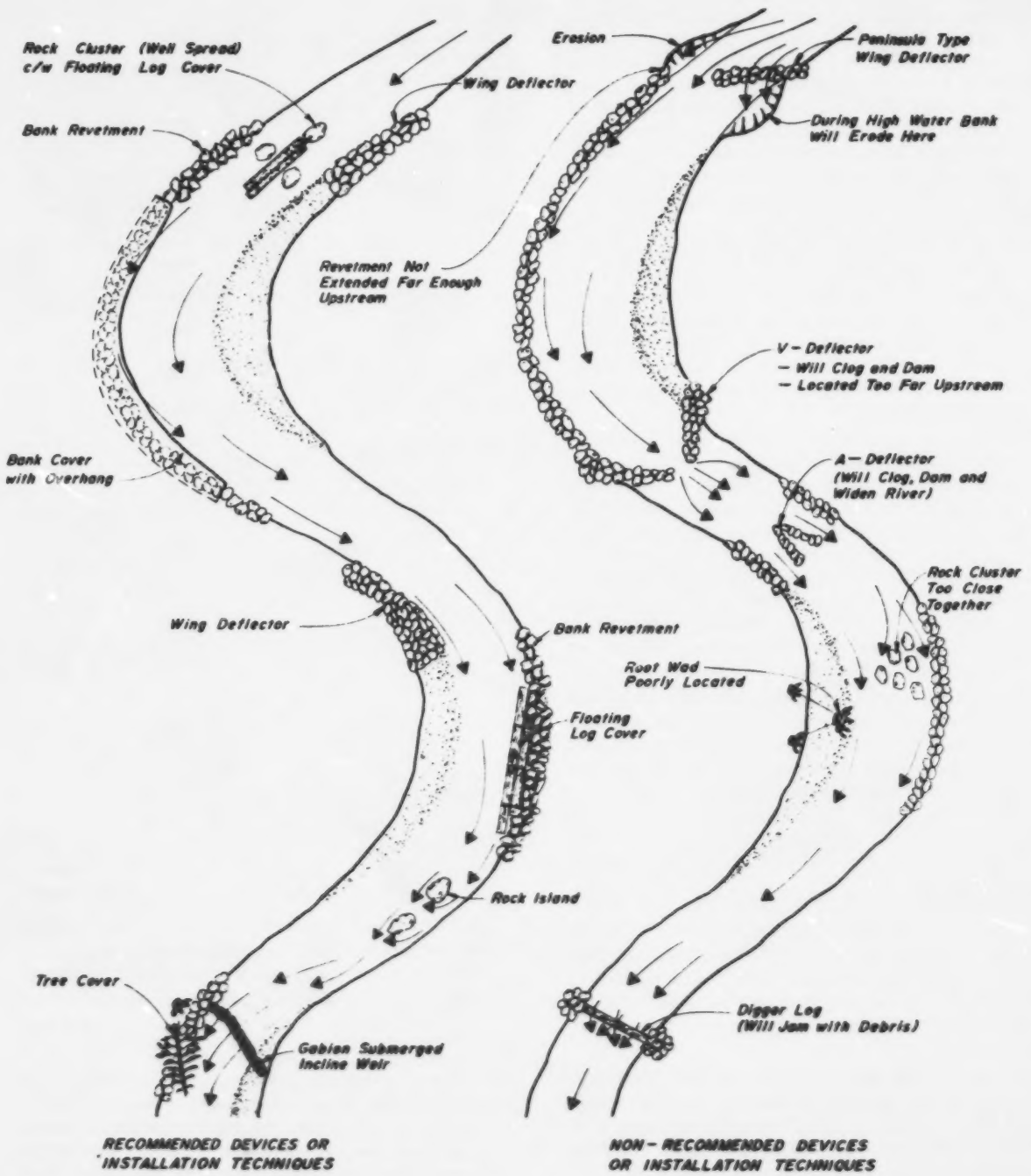


Figure 12.11 *Various recommended and non-recommended stream enhancement techniques (Adapted from White and Brynildson, 1967).*

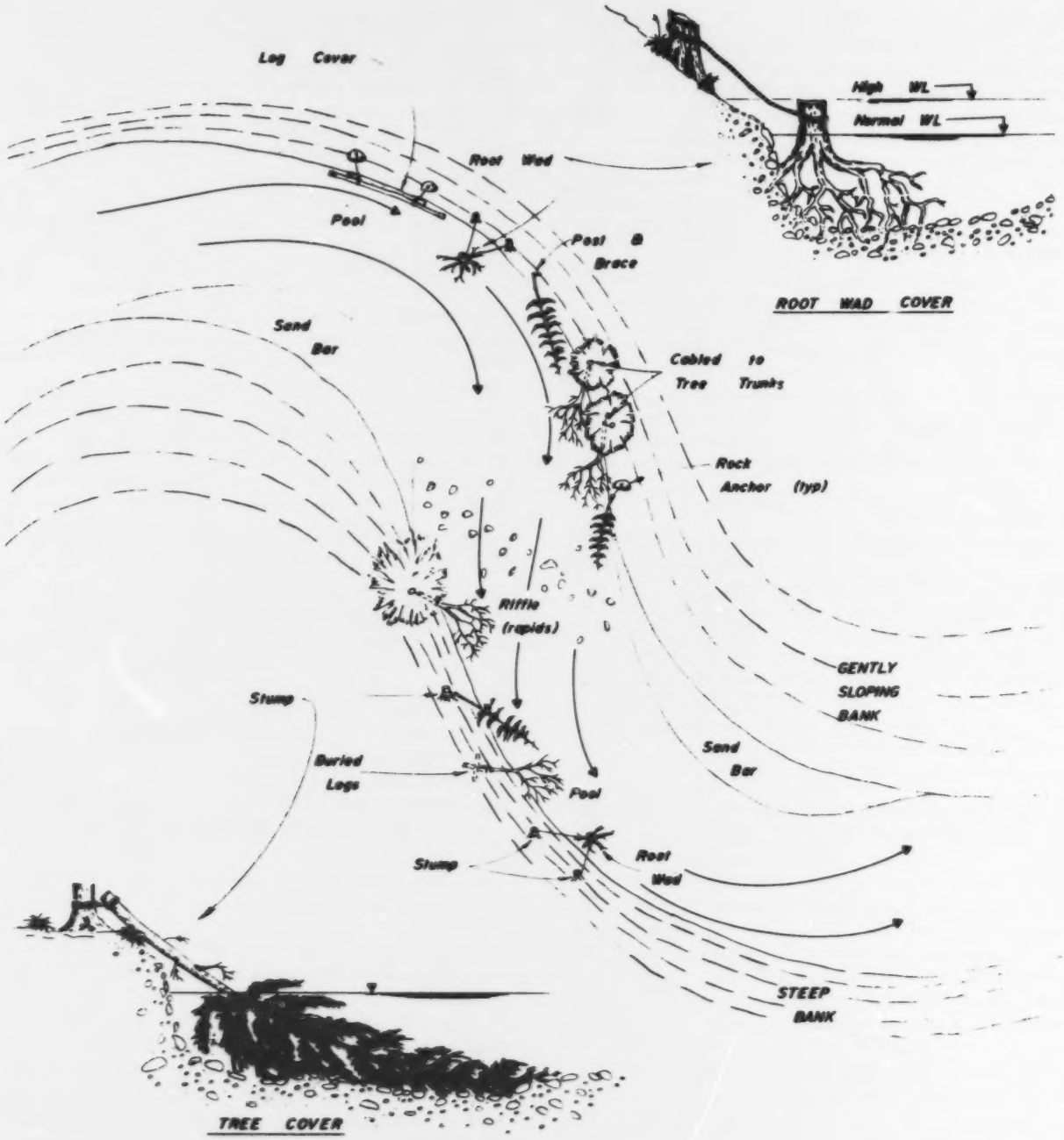


Figure 12.12 *Examples of where trees, logs and root wads can be located to provide cover for rearing salmonids. These devices are secured to the bank with cable. Stumps, trees, large rocks and buried logs can be used for anchors. Butt ends of trees must be kept above flood level to avoid snagging debris. Cable should be kept as short as possible, but approximately 0.6 m should be provided for free play and changes in water level. Regular maintenance and replacement are required for all items shown above due to natural decay (Adapted from White and Brynildson, 1967).*

A rip-rap revetment should always be placed as jumbled pieces of rock with numerous angles and openings between each piece, and protruding into the current. It should never form a uniform wall. The openings between rocks and the quiet back eddies formed by protruding rock faces provide juvenile fish with rearing sites and shelter from predators and stream freshets. Observations made in some of the rock-lined, artificial spawning channels in British Columbia, have shown that newly-emerged salmonid fry use the rip-rap located along the edges of the channel as a hiding place.

Rock revetments are almost always built in conjunction with other stream enhancement techniques. Wing deflectors and submerged weirs would not be effective if the opposite bank were not protected and stabilized with rip-rap (Figs. 12.5 and 12.10). Rock revetments also minimize the risk of erosion damage to adjacent private land or to fish located upstream and downstream of the structure. Streambank protection and stabilization is an essential consideration in the design and installation of stream devices.

Providing Cover

Some streams are deficient in natural cover. Bushes and shrubs, reaching over and into the water, provide excellent hiding areas for juvenile salmonids. Similarly, dead trees, bushes and branches which fall into the water can also provide stable cover. From these shelter areas, fish can safely dart into the current to obtain drifting food. They also protect fish from conflict with other individual fish. Every effort should be made to preserve the beneficial aspects of this type of cover. However, excess cover including accumulations of logging or windblown debris, can reduce salmonid production.

Several simple methods and devices are available to enhance this aspect of the fish's environment. Trees and large branches can be anchored to the stream bank to duplicate natural cover. Large root wads can be located and anchored at key locations in a stream (Fig. 12.12). Logs can be lashed together and anchored along a stream bank to form cover that will rise and fall with the water level (Fig. 12.5). These devices may be attached tightly to large boulders or bedrock by drilling holes and using rock bolts or anchors. Where the stream substrate is coarse, half-logs can be anchored and supported a few inches off the bottom to provide submerged cover for rearing juveniles (Fig. 12.13). The submerged half-log devices can be used in midstream or in any stable area where the substrate is relatively coarse and not susceptible to sand or silt deposition. Extra care must be taken when locating these devices to ensure that silts, sands and other fine debris do not bury the structure.

Large boulders, with natural overhangs and undercut faces, can be installed in stable pools to form permanent, natural cover (Fig. 12.14). Submerged logs lashed together and combined with carefully placed rock and cobbles to hold them in place, can be installed on a sharp stream bend to form overhanging cover (Fig. 12.15).

Guidelines concerning the construction and installation of cover devices in a stream are as follows:

(1) Cover should be incorporated with other stream enhancement devices such as rock clusters, overhangs, revetments opposite deflector wings and other techniques described in this guide.
(2) Anchor trees and root wads in a stream in a manner that avoids damming the flow.
(3) Anchor the butts of trees above high water, or in a manner that will not snag floating debris.
(4) When whole trees are used for cover, the fine branches must trail downstream with the butt securely anchored to the stream bank.

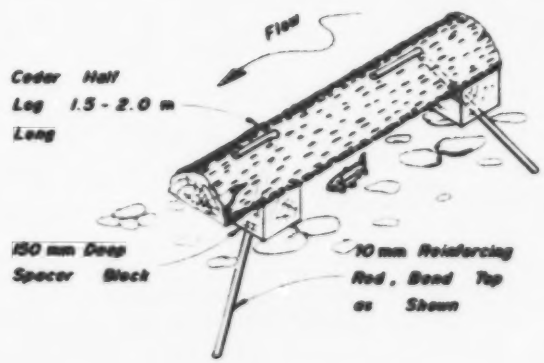


Figure 12.13 Submerged half-log structure provides cover for juvenile salmonids in small streams. Pre-drill log and spacer block on angle for maximum holding in stream substrate. Choose location carefully to avoid bedload deposition (Adapted from Hunt, 1978).

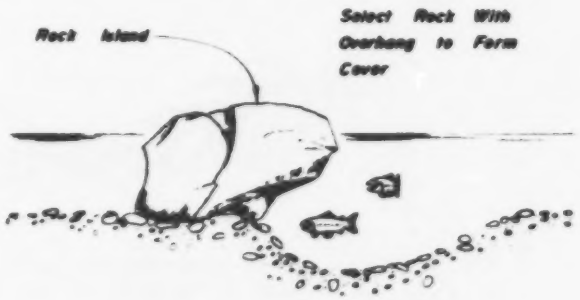


Figure 12.14 A large rock island forming a pool with cover. Choose rock with an overhang and position it in the stream channel to create cover. Locate the rock, or a cluster of rock on the outside of the curve to minimize bedload deposition.

(5) Trees, large branches and floating logs anchored along the stream bank must drag parallel to the flow.
(6) Floating log cover must be placed adjacent to a steep embankment to avoid the logs *hanging-up* on the bank when high waters recede.
(7) Cut trees, branches and floating logs have limited life because of decay and physical damage. These devices must be replaced and maintained on a regular basis. Cedar is the preferred species. Fast-rotting species such as alder should be avoided.
(8) Ensure that streamside trees are only used with the permission of the B.C. Forest Service or the private landowner involved.

An indirect form of cover, suited primarily for adult salmonids in a relatively stable stream, is the simple foot bridge across a stream (Fig. 12.16). In addition to providing cover for the fish, the foot bridge improves public access.

Many types of floating cover have been used in streams and artificial spawning channels. Floating cover often consists of cedar logs lashed together or formed into a simple raft made from timber or split cedar slabs. Plywood rafts, supported by styrofoam floats, have also been used. As these latter devices look artificial, they are best suited to man-made spawning or rearing channels.

In concluding this section on rearing habitat improvement, it must be stressed that the choice of a particular approach to enhancement must take into account the physical conditions and the availability of materials at each site. Examination of some streams may indicate that there is either no opportunity or need to create rearing habitat. It is therefore often necessary to obtain advice from experienced fisheries agency personnel before going ahead with a project. The key point to remember when undertaking any stream channel improvement is that a *conservative approach should prevail until adequate experience is gained.*

For species such as steelhead, with a long freshwater rearing phase, improvement efforts should usually be focused on habitat for the older and larger pre-migrant fish, ie. 1 and 2 year old parr, which are more likely to experience habitat limitations and will have a higher survival to the smolt stage. The following table, based on information from the Keogh River on northern Vancouver Island, provides a rough guide to survival rates which might be expected for steelhead at various life stages in freshwater:

Egg to fry	Fry to 1+ parr	Parr to smolt
4 - 18%	5 - 25%	50%

Improvement of Spawning Habitat

Before embarking on a project to improve spawning habitat one must first determine if it is warranted. For many salmonids, the availability of rearing habitat is usually the key factor affecting their production. Any effort to increase fry production, through improvement of spawning habitat, may be *completely negated* by the lack of suitable rearing area to support the additional fry. On the other hand, chum and pink salmon enter the ocean as fry with little or no freshwater rearing. For these species, improvements to the spawning habitat can be beneficial. There are also a number of lakes in British Columbia with underutilized rearing capability for species such as sockeye salmon, because of limited spawning area in the tributary streams. In these cases, expansion or improvement of the spawning area would lead to increased fry input to the lake rearing area and, subsequently, greater production of adults.

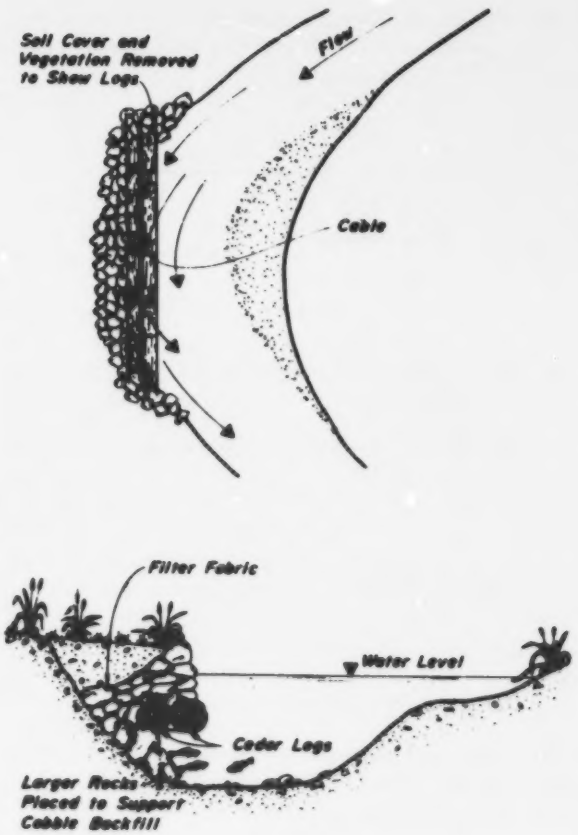


Figure 12.15 Bank overhang cover for a sharp bend in a stream. Device consists of 2 or 3 cedar logs lashed together and well anchored at each end.

Salmonids usually spawn in the shallow riffles. The female fish typically spawns at the crest of the riffle, depositing her eggs in several pockets, under 15-20 cm or more of gravel (Fig. 12.17). The spawning nest, or *redd*, usually covers an area of 2-3 square metres. Water flowing through the gravel serves two essential functions for the developing embryo: delivery of dissolved oxygen and removal of waste products. If the eggs or alevins are not killed or scoured from the gravel by floods or dug out by spawning fish, their survival will depend on (1) the water

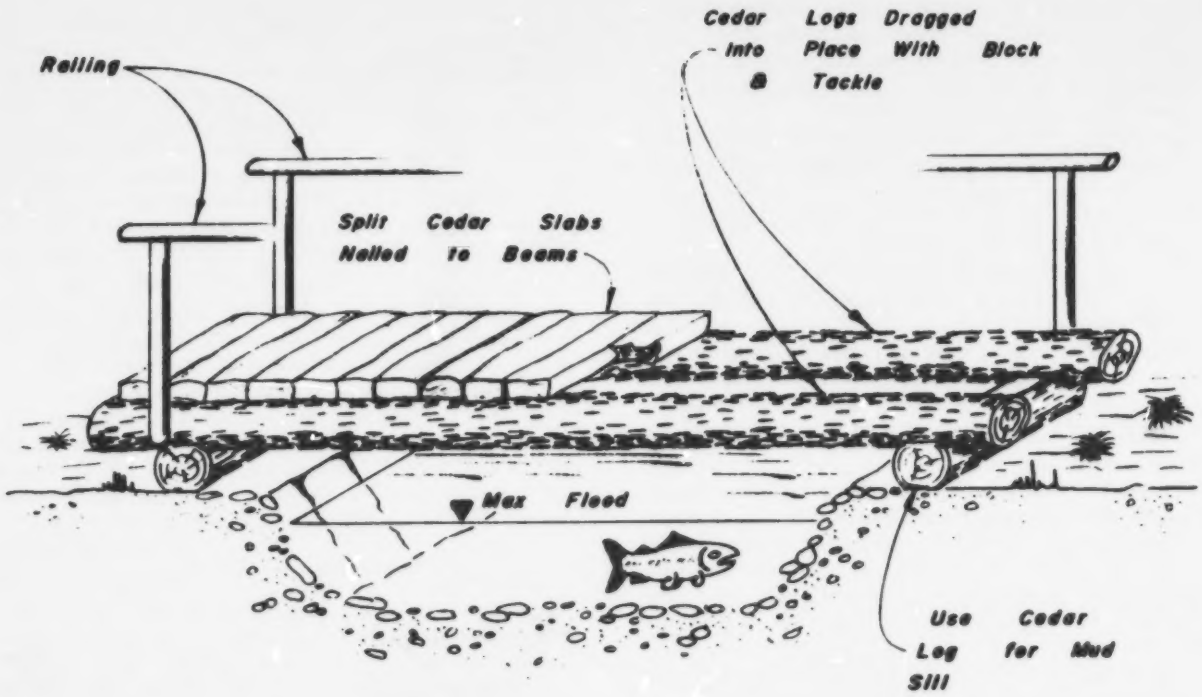


Figure 12.16 *A simple foot bridge over a small, stable stream can provide cover for adult fish prior to spawning. The bridge also provides access for stream assessment work and for anglers.*

velocity and dissolved oxygen level within the redd, and (2) sufficient pores or spaces to permit fry emergence up through the gravel. These conditions are governed by the amount of fine sand and silt which intrudes into the redd. An adequate intragravel water velocity would be about 5-10 cm per hour, an extremely low rate of movement compared to velocities above the gravel.

Variations in the slope and depth of the gravel bed govern the interchange of water between stream and gravel, and influence the velocity of flow within the redd (Fig. 12.18). In a stream section of increasing slope, such as from a pool to a riffle area, interchange tends to be down into the gravel. In a section of decreasing slope, the interchange is upward. The shape of the individual redd (Fig. 12.17) also promotes a strong, downward flow on its upstream side. However, in the unstable conditions prevailing in many coastal streams, the crests of redds will often be flattened by the shifts of gravel which occur under high flows. This reduces or eliminates the influence of the initial redd shape in promoting water exchange and intragravel flow.

Spawning salmonids exhibit a preference for certain water velocities, depths, and gravels. Water velocity appears to be the most important factor. As a general rule, large species and races of fish choose spawning locations of higher velocity and coarser gravel than smaller fish. Salmon and steelhead trout generally choose velocities in the range of 45-100 cm/sec measured at about 10 cm from the stream bottom. The larger species, such as chinook and chum salmon, will utilize velocities in the 60-100 cm/sec range whereas pink salmon generally prefer velocities of 45-60 cm/sec. Coho salmon and steelhead trout prefer velocities intermediate in the above range. As particular stocks of a single species may differ considerably in average size, the above information should be used only as a rough guide.

Though salmon and trout spawning occurs at stream water depths ranging from 15 cm to over 7 m, the major portion of spawning in small to medium sized streams takes place at depths of 30-60 cm.

The size composition of gravel in the spawning bed, which is a function of water velocity, will also depend on the species and size of fish. Measurements from the redds of chinook, coho and sockeye salmon in the Columbia River show that as fish size increases the proportion of large diameter gravel (over 50 mm) in the redd also increases (Table 5). The gravel composition in steelhead trout redds would, in the case of most stocks, compare with that given for coho salmon in Table 5. However, coastal cutthroat trout would generally use smaller gravel than that measured in sockeye salmon redds. Artificial spawning channels for salmon generally contain gravel of 12 to 120 mm diameter, from which all the finer material has been

Table 5. Average size composition of gravel in redds of three Pacific salmon species (Adapted from Andrew and Geen, 1960 and Burner, 1951). Approximate average weight of each species shown in brackets.

Gravel Size (diam.)	Fall-run Chinook (9 kg) %	Coho (4 kg) %	Sockeye (1.5 kg) %
Fines	10	8	12
3 - 12 mm	19	23	23
12 - 50 mm	38	43	51
50 - 100 mm	21	23	12
100 - 150 mm	12	3	2

screened.

Certain races of salmonids spawn in areas fed by groundwater, rather than surface water. This is quite common among chum salmon populations which frequently spawn in sloughs and blind channels with low surface water velocity. In these cases, the fish choose discrete areas of upwelling flow.

The following sections outline a variety of measures for improving spawning area. The approach taken will depend on the characteristics of the stream and intended life of the project. In planning spawning area improvement projects, one should also be aware of the potential for negative side effects on salmonid rearing habitat, particularly when heavy machinery is utilized. *Avoid overzealous clearing of forest debris and jams, and filling in small pools, all of which provide cover for rearing juvenile fish.*

Salmonids spawn in stream riffle areas primarily because of the good exchange of water between the intragravel and surface flow (Fig. 12.18). High water velocity in a riffle ensures that there will be little accumulation of fine material to interlock with the large particles. The gravel in the riffle in therefore relatively unstable. Because of this, addition of screened spawning gravel to a natural, uncontrolled stream is often unsuccessful. Unless prevented from moving downstream, the additional gravel will often be deposited in pools and around rocks and log jams, to the detriment of salmonid rearing habitat. In a typical small stream with a maximum width of 10 to 14 m, slopes in excess of 0.3% produce velocities that during freshets will readily move spawning gravel, particularly after it has been loosened by spawning salmonids.

The key, therefore, is to improve stream areas which have relatively stable flows. Some typical examples are:

(1) Stream outlets of lakes with limited inflow are often stable owing to the storage effect of the lake. During a storm, the lake will have sufficient storage capacity to buffer the high inflows, resulting in relatively stable flows at the outlet.

(2) Stream side channels with an adequate and stable base flow, and not subject to *flooding out* each year and filling with silt, are also a good prospect for spawning ground improvements for some species.

(3) Streams with a degree of man-made or natural flow control can be ideal for spawning area improvement. An example would be a stream which drains a series of lakes.

(4) Groundwater-fed streams receiving limited surface runoff often have sufficiently stable flows to permit

Figure 12.17 *A typical salmonid spawning nest or redd, showing egg deposition in a series of pockets which the female covers successively with gravel. Egg size is exaggerated for purposes of illustration (Adapted from White and Brynildson, 1967).*

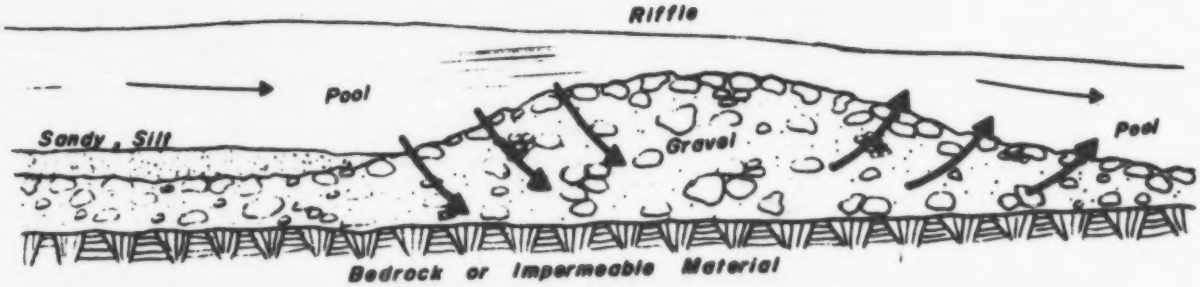


Figure 12.18 *Direction of water interchange between stream and gravel in a salmonid spawning riffle. Where the stream slope increases at the head of the riffle, water flows downward into the gravel. At the lower end of the riffle, where stream slope decreases, flow tends to be upward from gravel to stream (Adapted from Vaux, 1968).*

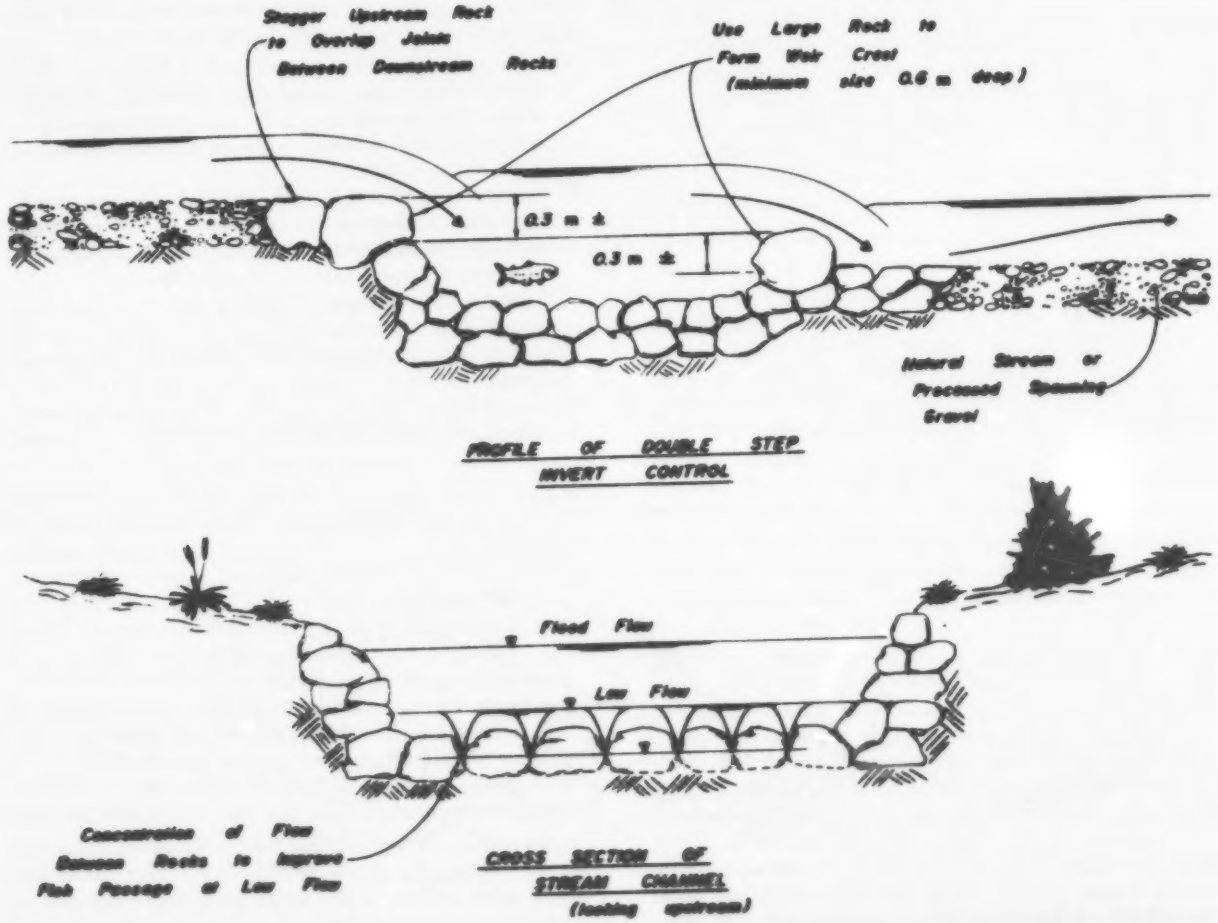

Stagger Upstream Rock to Overlap Joints Between Downstream Rocks
Use Large Rock to Form Weir Crest (minimum size 0.6 m deep)
0.3 m ±
0.3 m ±
Natural Stream or Processed Spawning Gravel
PROFILE OF DOUBLE STEP INVERT CONTROL
Flood Flow
Low Flow
Concentration of Flow Between Rocks to Improve Fish Passage at Low Flow
CROSS SECTION OF STREAM CHANNEL (looking upstream)

Figure 12.19 *Rock used to control grade in a channel and minimize the downstream movement of gravel. Abutments must be protected with rip-rap to prevent the stream from washing around the ends of the rock weir.*

spawning area improvement.

It is apparent that not just any stream can be enhanced by simply adding spawning gravel and attempting to stabilize the material in place. In fact, this technique would have limited application in most British Columbia streams, with their widely fluctuating flows. However, for those streams and side channels which are suitable, a number of techniques are available to stabilize the stream bed and minimize the gravel movement.

As outlined in earlier sections of this guide, one of the best materials to use for stream enhancement work is selected pieces of natural stone or quarry rock. A simple weir can be constructed across the channel, using carefully placed stone. The abutments or ends of the weir must be protected by rip-rap to at least 0.6 m above the maximum high water mark to prevent water from washing around the ends of the weir and flushing gravel, sand and silt downstream. The crest of the weir should be relatively level, with only the natural irregularities of each rock providing passages for fish to swim through. Where substantial grade must be eliminated, a double drop can be used (Fig 12.19). The techniques shown for the double-drop weir would also apply to the single weir installation.

It has been noted at several rock weir installations that most fish swim rather than jump over the weir. This occurs particularly during low stream discharge, when most of the flow is concentrated in the notches between rocks (Fig. 12.20). Spawning fish may cause gravel to move downstream and partially fill the pool below the

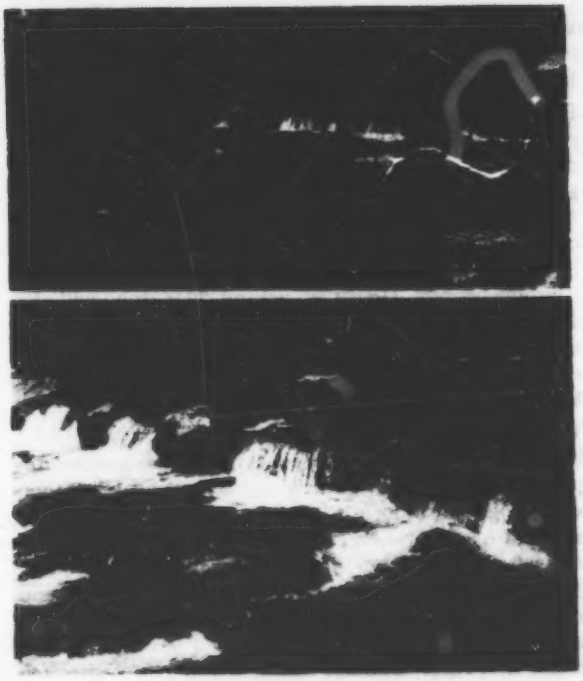


Figure 12.20 Rock weir controlling the grade in a river channel. Photograph was taken at very low flows. Fish usually swim upstream over the weir at the points where flow concentrates between rocks.

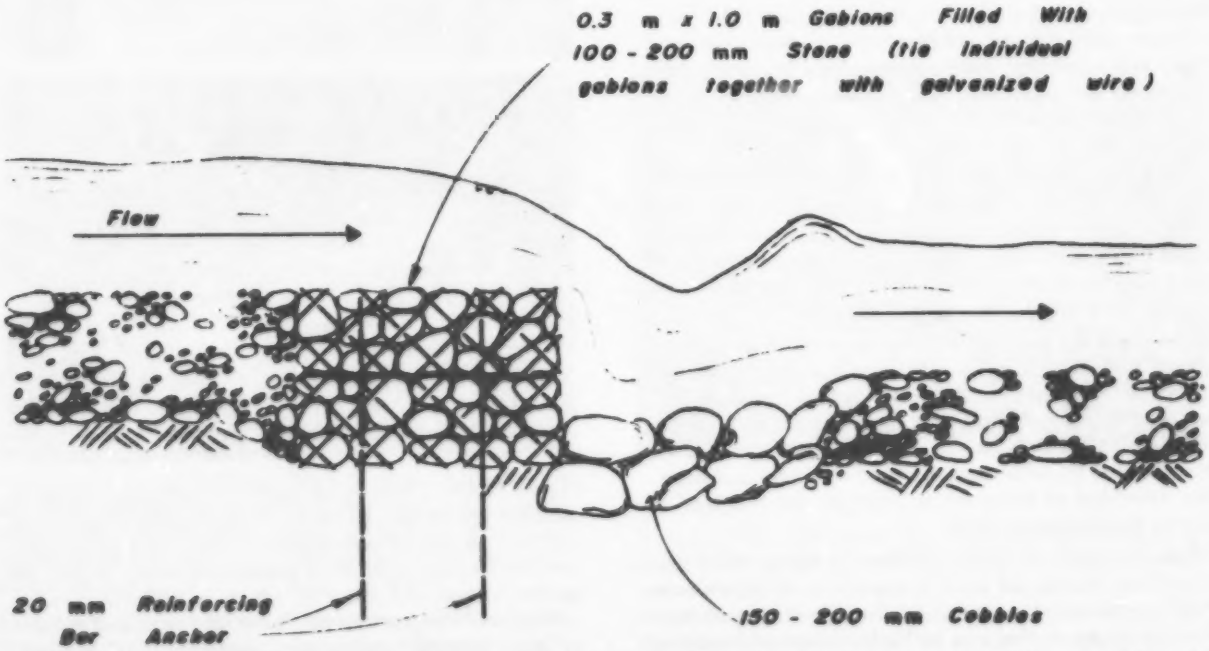

0.3 m x 1.0 m Gabions Filled With
100 - 200 mm Stone (tie individual
gabions together with galvanized wire)
Flow
20 mm Reinforcing
Bar Anchor
150 - 200 mm Cobbles

Figure 12.21 Gabion weir used to stabilize gravel and maintain channel grade. Space can be left between selected gabions to provide passage for migrating salmonids. Abutments must be protected with rip-rap to prevent washout. The small pool which forms downstream of the weir creates rearing habitat at low flow.

weir. Generally, the *plunge pool* below the weir will stay clear of gravel and most of the material will deposit against the downstream weir.

Experience in the northwest United States indicates that rock-filled gabions may be used in place of boulders to control channel grade. For this application, a galvanized gabion basket, approximately 3.5 m long x 1 m wide x 0.3 m deep is preferred. The wire baskets are filled with 10-20 cm diameter rocks. Quarry or shot-rock is normally used to fill the baskets, as the material is more stable and consolidates less. However, natural river stone will also suffice when quarry rock is not available. Gabion weirs may be used to trap gravel moving as natural bedload, or to hold screened spawning gravel which has been added to the stream.

When gabion weirs or invert controls are installed, the bottom gabion should be recessed in the streambed approximately 30 cm, and successive layers of gabions then wired together to form a homogeneous structure. Small spaces are left between gabions in the top row to provide notches of concentrated flow for the fish to swim through. Alternatively, the gabion weir can slope from each end towards the center to concentrate flow for fish passage at low water levels. Where a gabion weir joins the stream bank, it is recommended that the weir penetrate each bank at least 1 m. The entire abutment should then be protected with rip-rap. Fig. 12.21 shows a typical stream bed profile, using a gabion weir as an invert control. The various steps in constructing a gabion weir are shown in Fig. 12.22. Gabion supply firms can also provide manuals explaining the various installation techniques.

Since gabion and rock weirs are not watertight, they promote good exchange of flow between the stream and the gravel spawning bed for a considerable distance upstream of the structure. The hydraulic conditions are often equal to or better than those which exist in a natural stream riffle. For this reason, spawning salmonids show a distinct preference for the area immediately upstream of the invert control.

Used or reject precast concrete curb can also be incorporated into a weir (Fig. 12.23). These devices normally work well for drops of 25 cm or less, and can be used to control the grade of the channel.

Submerged log weirs have also been used to stabilize gravel. Fig. 12.24 shows an under-utilized trout spawning stream where gravel was added and submerged logs were installed to prevent gravel shift and to form shallow holding pools for maturing adults. The relatively stable flows, as evidenced by bank vegetation and channel characteristics, provided an excellent opportunity for this type of stream enhancement work.

When the grade in a stream channel is being stabilized, regardless of material used, a good rule of thumb is to duplicate the existing average grade of the stream section. For side channels that may be backwatered as a result of debris or bedload deposition at the downstream end, the existing grade may not be clearly defined. In this situation, or in other areas where new channel grades are required, slopes of between 0.15 and 0.3% should be maintained. The lower limit should be used for smaller

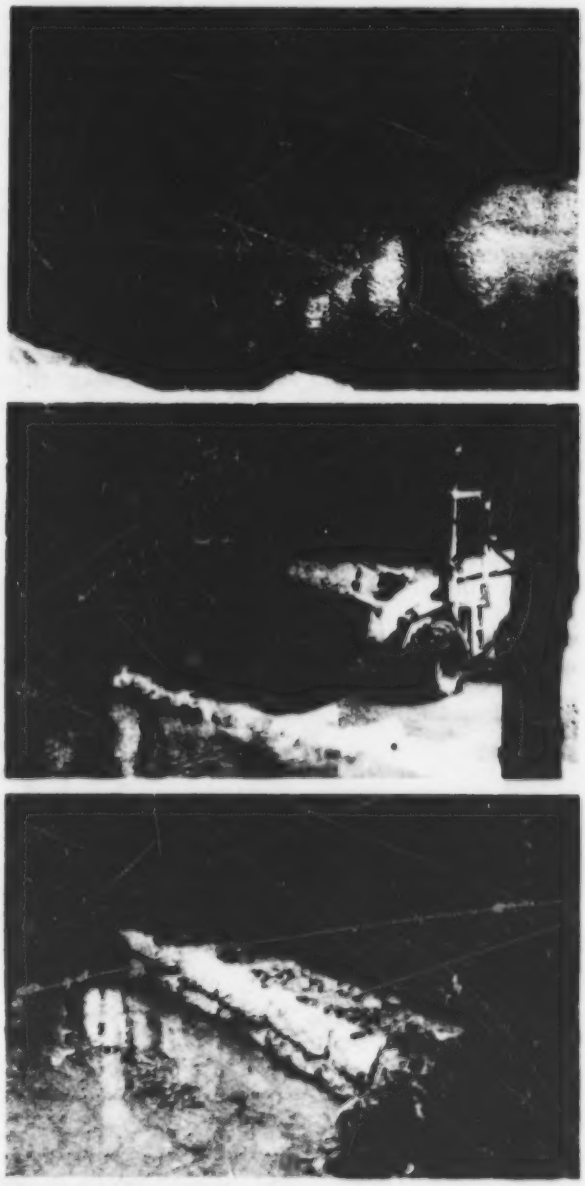


Figure 12.22 *Three basic steps for installing gabions to stabilize gravel and maintain channel grade: (upper) at appropriate time of year excavate trench and install gabion baskets fabricated from galvanized wire; (centre) fill gabion baskets with 100 – 200 mm stone, either by hand or with a front-end loader; and (lower) tie top row of gabions to layer beneath, and protect abutments with rip-rap. Spaces can be left between gabions on the top row to facilitate fish passage at low flows.*

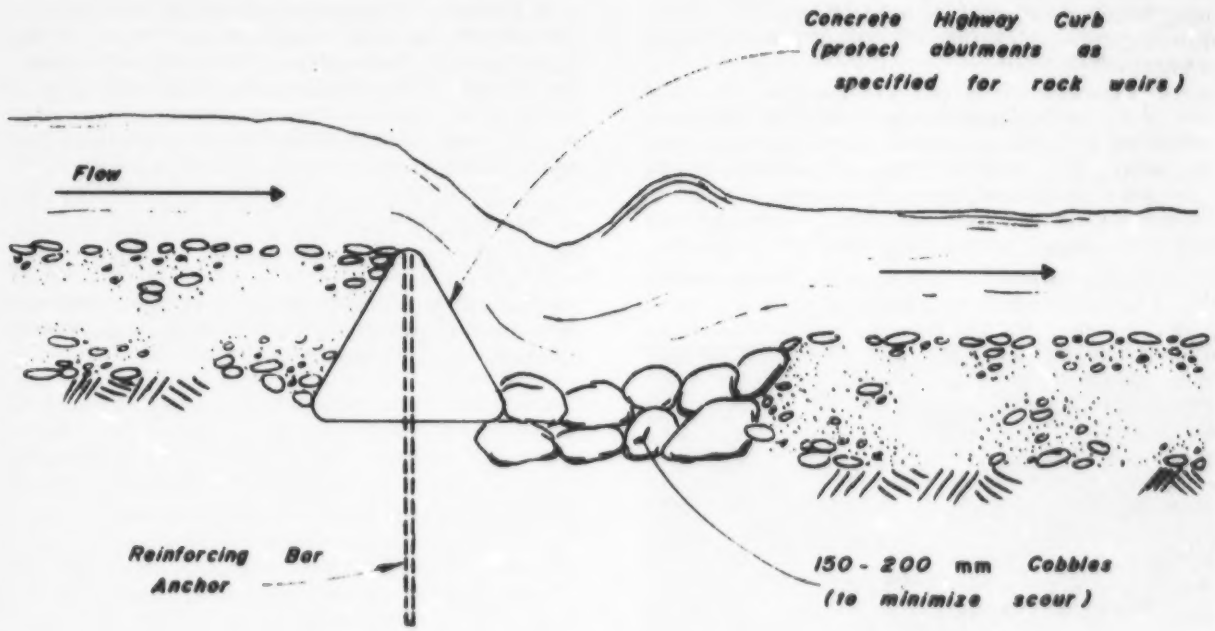


Figure 12.23 *Concrete highway curb used to stabilize gravel and maintain channel grade. The weir can be sloped towards the center to facilitate fish passage at low flows. This type of weir is ideal for drops not exceeding 230 mm and for streams where large rocks are not plentiful.*

salmonids, and the upper limit for the larger species such as chum, chinook and large steelhead. If spawning gravel is added to these sections, a well graded mix of 12-120 mm diameter washed gravel is preferred (see Table 5).

For stream or side channels which experience few freshets, the gravel substrate will eventually accumulate fine material and become less productive as a spawning area. A few selected areas of streams or side channels can be carefully scarified with a small bulldozer during relatively high flows to remove silt and break up the natural compaction of spawning beds. To avoid damaging eggs or alevins in the gravel, the foregoing stream work must be carried out only at specific times of the year. In addition, care must be taken to avoid filling natural pools or grading riffle areas in such a manner that they become unstable during subsequent freshets. Because of the potential for detrimental impacts, especially to salmonid rearing areas and food organisms, gravel scarifying and use of machinery in streams should only be carried out under the direct supervision of the fishery resource agencies.

A less hazardous method of cleaning gravel in small streams or side channels is to utilize a portable high-pressure fire pump with a steel pipe nozzle that will penetrate the stream bed and flush fine silts and sands to

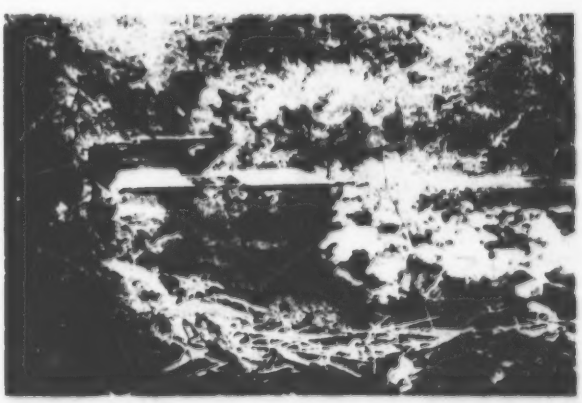


Figure 12.24 *The stable flow regime of this outlet from Ruby Lake on the Sechelt Peninsula provided an ideal situation for trout spawning area improvement. Submerged logs were used to stabilize spawning gravel added at selected locations along the stream. Overhead cover was installed to obtain better distribution of spawners over the improved area.*

the surface. The fine material is then washed downstream by the current to eventually collect in such areas as point bars, backeddies and pools. This method is preferable to using heavy construction equipment because existing spawning and rearing habitat is less likely to be disturbed or impaired.

Several government agencies have experimented with specialized hydraulic equipment for removing the fines from gravel. This equipment has been used primarily to clean gravel in artificial spawning channels. Because of the complex and specialized nature of the equipment, this type of operation is beyond the scope of this guide.

Resting pools and cover are also important for the protection of salmonids which must hold and ripen in streams prior to spawning. Holding fish will search out natural and man-made pools, and overhead cover such as overhanging banks, bridges and log jams that will provide protection from predators and interference by man. Some species, such as chum salmon, may only be in the river 7 to 10 days before they ripen, spawn and die. If the fish are delayed, or constantly frightened and driven off the spawning areas, the females may die unspawned. Other species, such as the chinook salmon and steelhead trout, may be in the stream for several months before spawning. These fish are particularly susceptible to predation and injuries which can result in prespawning mortality.

In a freshwater environment injured salmon deteriorate rapidly. Wounds become fungused, resulting in death before spawning. The importance of protected resting pools and adequate cover for spawners cannot be overemphasized. Accordingly, the techniques described earlier for increasing pool area and cover apply just as well to enhancing the fish's spawning habitat.

13. SIDE CHANNEL DEVELOPMENT

In most of the larger river systems, side channels are important spawning areas, particularly for chum and coho salmon. Their value as summer and winter rearing habitat for coho salmon and cutthroat trout is also being recognized. Under most circumstances a side channel provides more stable flow and temperature regimes than the main stream. Many of the side channels used extensively by salmonids are protected from extreme high flows by build-up of gravel or a log jam at the upstream end. These channels often derive a major portion of their flow from either groundwater or seepage from the adjacent stream.

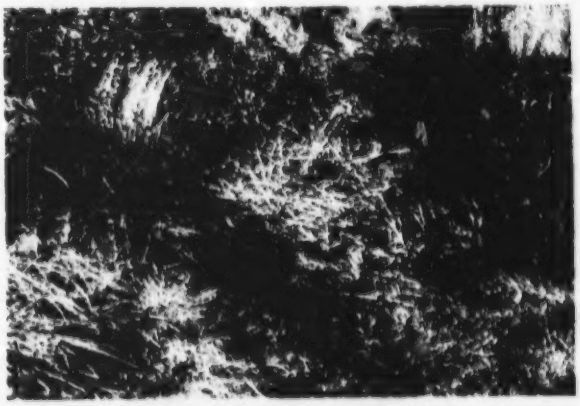
Inadequate water flow is generally the factor limiting salmonid fry production in a side channel. Flows may be too low in the fall, either to permit access for adults, or to cover much of the available spawning gravel. Low flows in the winter or spring may also leave many redds isolated from the wetted channel, thereby subjecting embryos to dessication or freezing, and possibly trapping large numbers of fry within the gravel.

For the purpose of this guide it is necessary to distinguish between side channels that are relatively stable and seldom experience flood flows, and those which each year carry a substantial proportion of the stream's peak flow. To successfully improve spawning conditions in this latter type of side channel requires a sophisticated water intake, a settling basin, outlet works, and often the addition of spawning gravel. The resultant facility would be essentially an artificial spawning channel, a technically complex enhancement method used by the government fishery agencies. Owing to the amount of detailed engineering and design required, a full description of this technique for improving side channel spawning habitat is beyond the scope of this guide.

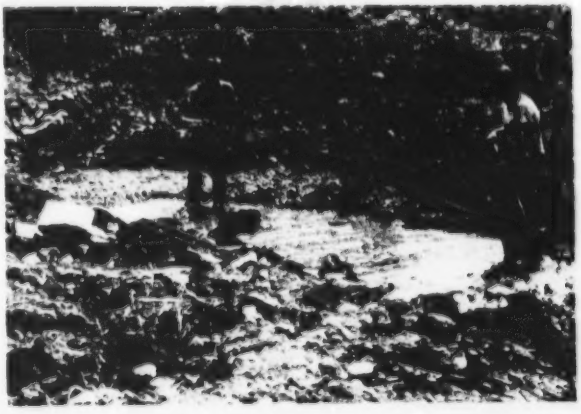
In contrast, some side channels are fed solely by river seepage, groundwater or a combination of both. These channels are relatively stable, being flooded out only in occasional years of high water. The flow into these channels can be increased by concentrating individual seepages into one stream. For example, an impervious underground cut-off can be installed at the upstream end of the side channel to force subsurface flows to the surface, thereby increasing flow in the channel. Such materials as hypalon, polyvinyl chloride and polypropylene sheets can be used as a buried cutoff. When the cutoff is tied into an impervious layer below the stream bed, the surface flow will often increase. Another method is to excavate a large pool at the upstream end of the channel to intercept the subsurface flows. Because water follows the path of least resistance, the pool will tend to increase the flow of groundwater coming to the surface at the upstream end of the channel. The collection pool could also serve to hold spawning adults or overwintering juvenile salmonids. Adult fish would mature in the pool and drop back to spawn in the channel below.

Once an adequate flow has been established, the side channel can be improved by establishing an effective width and depth, installing gradient controls or weirs if the channel is too steep, scarifying the existing gravel, adding either processed or bankrun gravel, constructing pools with cover, and improving fish access. These techniques have all been described in preceding sections.

Many side channels only require the removal of forest debris and logs to allow fine silts and sands to be removed by the resultant increased velocity. Often the removal of grasses and other vegetation encroaching on a silted side channel can restore it as a productive spawning area (Fig. 13.1). Addition of a few large boulders, wing deflectors and pools, could increase the rearing capacity of the side channel shown in Fig. 13.1.



BEFORE



AFTER

***Figure 13.1** Debris, silt and encroaching vegetation were removed from this side channel and gravel added to restore it as productive spawning area for chum salmon. Natural vegetation will be re-established on banks. Side channels with good rearing habitat should not be disturbed.*

In some cases the bottom of the side-channel or *invert* level can be completely lowered. This results both in the removal of silt and an increase in base flows. However, this technique must be approached with caution. If the channel invert level is excavated too low the main stream could backwater the rehabilitated channel, creating low velocities and an even greater silting problem.

The flow in a side channel can be very low, thus producing insufficient velocities to scour pools and establish the normal pool-riffle meander pattern that exists in the main stream. Due to the relative stability of flow, pools can be located almost anywhere without the usual concerns for stream hydraulics. Pools may be created by using a submerged log or timber crib, or by placing oversized rocks to form a depression in the channel bottom. Floating cover can be installed at most locations along the channel, because these devices would not be exposed to the hazards of floating debris and logs which exist in the main river. These improvements will not only provide holding areas for adults, but also rearing space for juveniles.

The side channel cross-section must be designed to provide sufficient depth for adults to spawn. Depending on the species, the minimum depth could be as low as 10-15 cm. The desirability for spawning is also affected by stream velocity and the amount of groundwater and subsurface flow that percolates up through the bottom of the side channel. The groundwater influence in side channels is often the key factor in creating suitable spawning areas, particularly where surface velocities are inadequate.

14. STREAM FLOW CONTROL

Stream flow is the major environmental factor affecting the survival and production of coastal anadromous salmonid populations. Flow levels affect salmonids in several ways. Extended periods of low flow can delay the movement of adults into streams, draining their limited energy reserves and affecting upstream distribution and spawning success. High winter flows can cause mortalities of eggs, by scouring the gravel or depositing sediment in the spawning beds. Overwinter survival of juvenile fish may also be reduced by the scouring of shelter and deposition of bedload in their winter habitat. Low winter flows can result in the freezing of eggs or stranding of fry in spawning beds which were used at higher flows in the fall. Prolonged periods of low flow in summer reduce available rearing area for juveniles (Fig. 14.1). Fluctuations in the abundance of adult coho salmon have been related to stream flow levels during the juvenile stage.

A project designed to alleviate the above problems in order to increase salmonid production has been implemented at Big Qualicum River on the east coast of Vancouver Island. The Big Qualicum river had a history of wildly fluctuating flows, from extreme floods in winter to low flows in summer. Survival of salmonids in the system, particularly the chum and chinook salmon, also fluctuated greatly, with instability of flow being the major contributing factor. Although a complete description of this project is beyond the scope of this guide, the basic operational features are shown in Fig. 14.2 to illustrate the concepts of this scheme in which the flow and temperature of an entire river are regulated for the benefit of salmonids.

Horne Lake in the headwaters of the Big Qualicum River, is used as a water storage reservoir. The lake can be drawn down up to 20 m below its natural level by means of a gate shaft, with three separate intakes at different elevations (Fig. 14.2). Water drawn into the gate shaft passes through a 500 m long tunnel to a valvehouse, where it is released back into the natural river channel below Horne Lake. A dam in the lake outlet also enables storage of water above the natural lake level. The multi-level intake system provides a means of alleviating the naturally high summer temperatures with cool water drawn from the depths of Horne Lake.

While stable flows are being maintained in the lower Big Qualicum River, the level of Horne Lake fluctuates in a regular annual pattern. The lake level rises as high flows during late fall and winter are held back, and drops gradually over the following spring and summer when inflow to the lake is much lower than the regulated outflow to the river below.

Despite the advantages of artificially stabilizing stream flow, there have been few attempts to do so for the benefit of salmonids. Usually it is not economically attractive to develop reservoir capacity adequate for flood protection exclusively to enhance salmonid production. However, there is a promise in augmenting extreme low flows because of the relatively small amounts of storage capacity required. For salmonids with a freshwater rearing phase, survival and production can be improved simply by increasing low flows in the late summer and early fall. Many natural lakes and ponds offer opportunities to increase minimum flows at costs which would be justified by the resulting increase in smolt production. In one such project, flow conditions for both rearing juveniles and migrating adult salmon were improved by releasing approximately 0.5-1 m^3/sec (cubic metre per second) for 4 to 6 weeks through a simple gate structure shown in Fig. 14.3. This project involved blasting a small opening through the bedrock shore of a lake and installing a simple, reinforced

Figure 14.1 The Keogh River, northern Vancouver Island, under extreme drought conditions in the headwaters. This stream is a good producer of salmon, steelhead and Dolly Varden. Like most coastal streams, it experiences extremes of flow, with a 2000 – fold difference between recorded maximum (200 m^3/sec) and minimum (0.1 m^3/sec) flows at the river mouth.

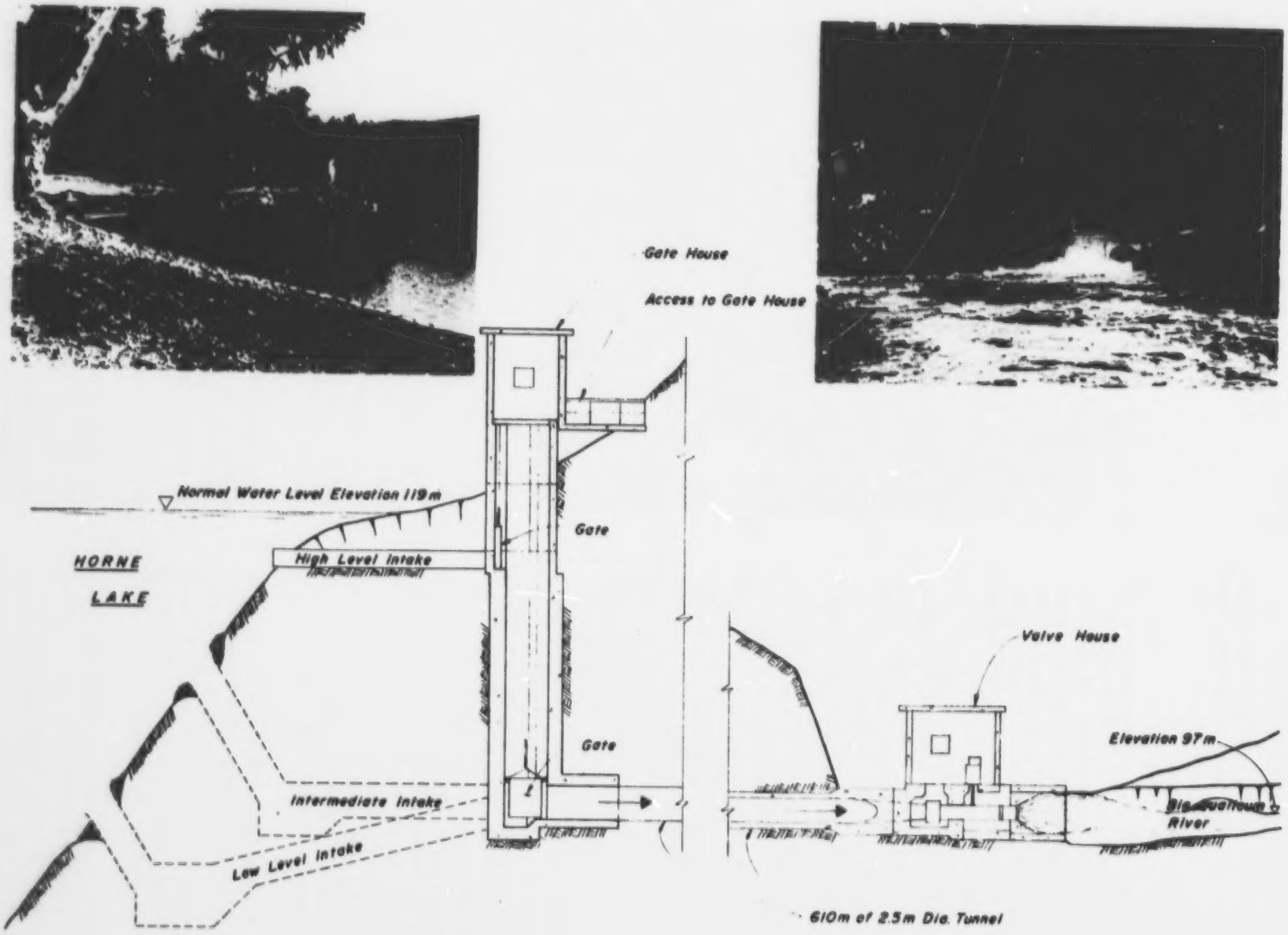


Figure 14.2 *Flow and temperature control for an entire system, the Big Qualicum River on Vancouver Island. The lake is used to store flood flows and two large valves at the downstream end of the tunnel regulate flow to the river. Temperature control is achieved by mixing water from the three intake levels.*

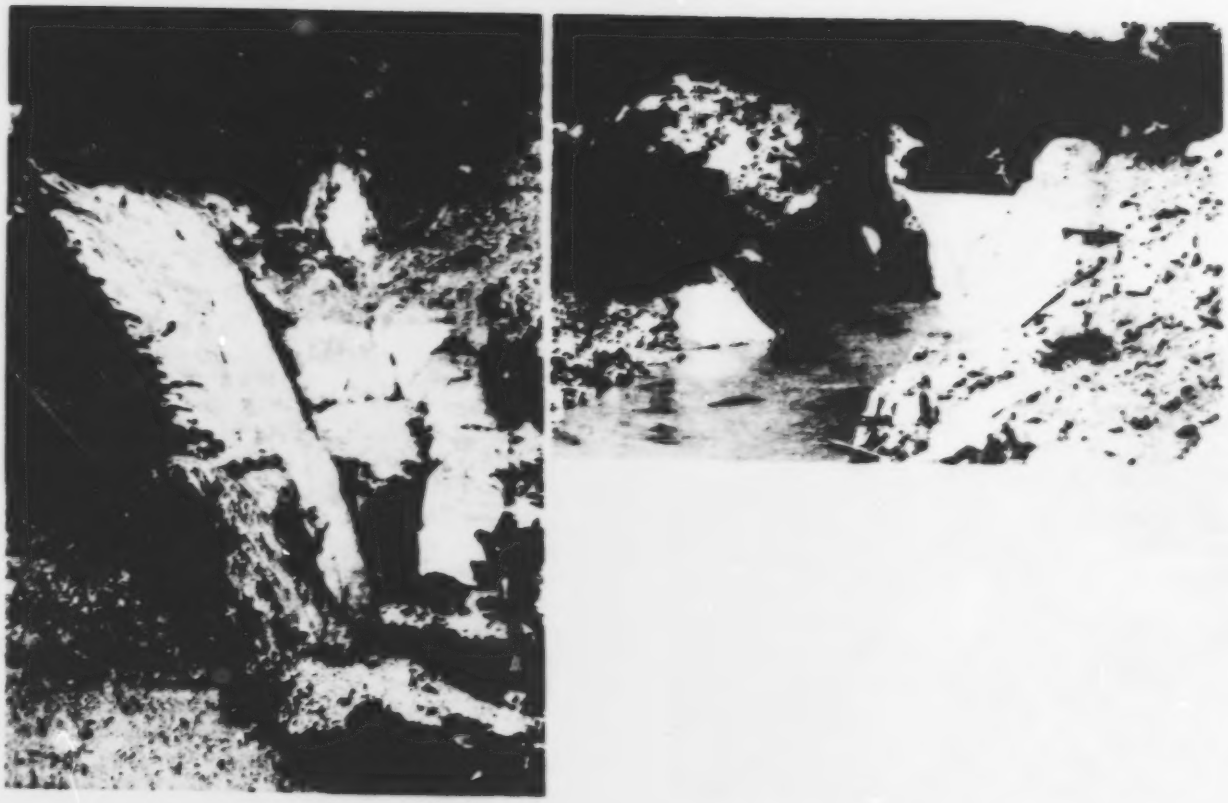


Figure 14.3 A small flow control structure provides increased flows during the summer and early fall to improve spawning conditions and rearing habitat for coho and steelhead juveniles. The left photograph shows the initial construction stages of an open cut channel which was blasted through bedrock to allow water to be drawn from the lake. The right photograph shows a simple, reinforced concrete wall installed with a manually operated sluice gate to control the discharge from the lake.

concrete wall with a manually-operated sluice gate. The entire project was completed in 6 weeks with a 3-4 person workforce. It has improved summer flow conditions in the stream for the past 14 years, at minimal operating and maintenance cost.

This type of small-scale flow control project can also be used as a reliable water supply system for streamside incubation facilities. By incorporating a pipe and control valve in the dam structure, a clean and reliable gravity water supply can be provided to operate fish facilities. This concept can also be extended to small dams and water impoundment structures that have been constructed for other water uses.

Fig. 14.4 shows a small impoundment dam constructed of handmixed concrete and boulders. The flow from the small, 28 hectare (69 acre) lake behind this dam is controlled by an adjustable plate over the end of a 10 cm diameter pipe set in the base of the dam. This structure was constructed to increase the base flow in a small creek on Vancouver Island, and so improve the rearing conditions for juvenile coho salmon and trout. By storing the spring runoff, an additional .04-.06 m^3/sec (1.5-2 cubic feet per second (cfs) are available during the summer drought, when the outlet creek would normally be almost dry. Such a flow can sustain a sizeable population of juvenile coho salmon over the summer period.

Water impounded behind beaver dams provides another opportunity to improve on natural stream flows. This approach, which has been used successfully by the New Hampshire Fish and Game Department, involves the installation of *beaver pipes* through the dam (Fig. 14.5). A timber box is used to form the pipe. The bottom of the box is slotted to allow water to enter, while the upstream end of the box is closed. In the majority of installations, the beavers concentrate their efforts on trying to block the downstream end of the square pipe without success. It was reported that if the upstream end were blocked and water allowed to enter the box or pipe through narrowly-

Figure 14.4 A three foot high dam constructed of hand-mixed concrete and boulders. The dam provided storage in 27 ha (69 acre) Matheson Lake, Vancouver Island, to increase summer flows for rearing juvenile coho and trout.

spaced slots on the bottom, the beavers were unable to detect the sources of water loss.

A modification of the beaver pipe described above utilizes plastic polyvinylchloride (PVC) sewer or water pipe. Numerous slots can be cut into the wall of the pipe to allow water to enter the pipe and discharge through the dam. Plastic pipe can be readily slotted using ordinary tools, and the material is light and relatively inexpensive.

General guidelines and installation techniques for installing a system of pipes through a beaver dam are as follows:

(1) The pipes should extend a minimum of 5 m into the pond with a minimum slope of 4% towards the bottom. The distance between the bottom of the pipe and the pond bottom must not be less than 30 cm.

(2) The pipe should be placed through the dam where the depth of the pond is greatest. Where two or more pipes are used, the inlet ends of the pipe should be located as far apart as possible to discourage beavers from burying the ends by widening the existing dam.

(3) The area of the slotted inlet section should be at least twice the cross-sectional area of the pipe. For a wooden box pipe, the opening between slots should not exceed 20 mm. With PVC pipe, the lower section of the pipe should be slotted to provide the gross open area specified above. Closely-spaced 3 mm slots can be readily cut into the wall of the pipe with a multiblade saw.

(4) The installation must be inspected a few days after initial installation to check for correct operation, and thereafter approximately once each month for periodic maintenance.

Another modification of the beaver pipe utilizes flexible, high density polyethylene pipe to siphon the water over the dam. The pipe would be slotted and capped as described above, but would not have to be installed through the body of the dam.

In a similar manner, small lakes and ponds can also be used to augment low flows in late summer and early fall. In this regard, the methods described for draining water from beaver impoundments can be applied equally well to other sources of ponded water.

The approximate volume of water which can be stored in a small lake or pond can be estimated from a knowledge of the lake area and the depth of storage available. For example, the number of days that a controlled flow of 1 cubic foot per second (cfs) could be released would be estimated by the following formula:

$$\text{no. of cfs-days} = \text{lake area (acres)} \times \text{available storage depth (ft)} \div 2$$

The metric equivalent, expressed in cubic meters per second (m^3/sec), would be calculated as follows:

$$\text{no. of } m^3\text{/sec-days} = \text{lake area (hectares)} \times \text{available storage depth (m)} \div 8.6$$

As this simplified method makes no allowance for any increases in lake area due to increased water surface elevation, it would tend to underestimate the potential amount of storage available. However, evaporation losses could counterbalance this tendency.

Construction of a storage dam in a lake outlet could result in higher peak lake levels and, in some cases, flooding of valuable timber or private property. The planning of any water storage project must therefore include an assessment of potential impacts on lake shore areas, and approval from appropriate government agencies such as the B.C. Water Rights Branch.

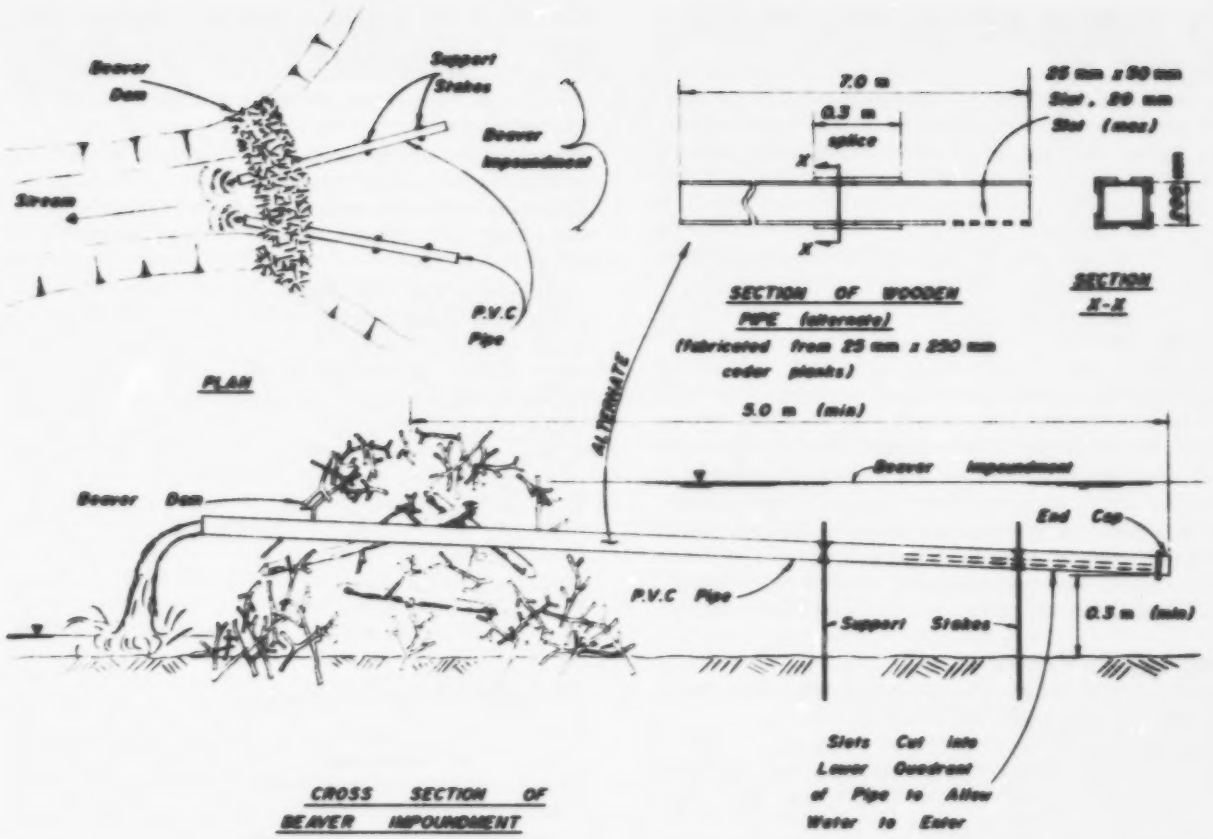


Figure 14.5 *Slotted PVC pipe can be used to drain water from a beaver dam impoundment. The pipe must be capped on the upstream end and slotted on the underside with fine openings to allow water to drain from the pond undetected by beavers. Low summer flows can be improved for rearing salmonids by the controlled release of water from the dam.*

15. INCREASING THE FOOD SUPPLY

Though salmonid enhancement in streams has focused on the quantity and quality of physical habitat, it is generally considered that increasing the available food supply would also enhance production of stream-rearing species. However, measures to increase salmonid food supplies are still in the experimental stage, because the subject is complex and the benefits and costs of the various enhancement techniques have not been established.

Aquatic insect larvae, which comprise most of the juvenile salmonid diet, depend for their food supply on two main sources: production of algae or aquatic plants on the stream bottom; and organic material from the land, in the form of decomposing plants (primarily dead leaves) and dissolved organic matter (Figs. 6.4 and 6.6). Dead leaves and organic material support populations of bacteria and fungi, on which the herbivorous insects graze.

In the following sections we briefly describe certain techniques which have been applied to indirectly improve aquatic insect production, as well as the instream feeding approach to augmenting the natural food supply.

Inorganic Enrichment

In comparison to interior streams, coastal streams in British Columbia tend to be unproductive in terms of algae and aquatic insects. The two principal elements governing algal production, phosphorous and nitrogen, are generally present at low levels because of the high runoff and the underlying geology. Experiments have been conducted on a Vancouver Island stream to determine the effect of increasing either phosphate or nitrate levels, and combinations of the two elements, on algal producton. These experiments, which were conducted in summer, demonstrated that in artificial stream channels algal production could be increased by controlled addition of inorganic phosphate and nitrate, in particular ratios. The level of phosphate appeared to be the main factor limiting algal production under natural conditions. Nitrate has been shown to have an additional role, however, in promoting the decay of leaf litter which in turn increases the abundance of bacteria and fungi for grazing insects.

The research conducted in this field to date must be considered preliminary. Although the more fertile streams appear to support greater abundances of rearing salmonids, it is not known how much increases in algal production from fertilization would affect populations of insects and, ultimately, salmonid fish. Experimental studies are being conducted to determine the precise amounts of nutrients required, so as to avoid concentrations which are toxic or which promote the growth of undesirable algae such as the filamentous species.

Organic Enrichment

Organic enrichment involves the addition of organic material which enhances, either directly or indirectly, the production of aquatic insects. The addition of grain and leaf material to stream riffle areas has been found to increase both the numbers and growth of aquatic insects. Likewise, addition of dissolved sucrose to an experimental stream increased bacterial growth, which in turn produced a several-fold increase in the production of certain insects and trout.

These studies were conducted at a small-scale experimental level. As yet, no pilot projects have been undertaken to determine either the technical or economic feasibility of organically enriching a natural stream to increase salmonid fish production.

Organic enrichment of streams may also occur inadvertently from human activities. Small streams situated in urban or agricultural areas can become enriched from inputs of domestic sewage, runoff from fields grazed by livestock, and leaching of phosphorous and nitrogen from soils to which fertilizer has been applied. Where inputs of organic materials and nutrients from these sources are relatively low, they will probably increase the food supply for juvenile salmonids through increased production of algae and aquatic insects. However, in cases where stream productivity is already high, additional nutrient input could be harmful. Extensive growths of filamentous blue-green algae may develop, the decomposition of which could reduce dissolved oxygen to marginal levels for salmonids.

Supplementary Feeding

Hand feeding of juvenile coho salmon has been carried out at several streams in southern British Columbia, in attempts to increase smolt output. This supplemental feeding has been conducted from May until November, when feeding activity declines due to low temperatures. Either prepared commercial fish food or frozen euphasiids, a shrimp-like marine crustacean, have been used.

Proper assessments of supplemental instream feeding projects have been limited to date. Research conducted at one site showed that both the numbers and average size of coho fry could be increased by supplemental feeding. However, there was a strong indication that the increase in population density achieved during the summer and fall period could not be sustained over the following winter and spring, up to the time of seaward migration. It appeared that the amount of suitable overwintering habitat for coho salmon juveniles ultimately governed smolt production from that stream.

The various approaches to increasing salmonid production from streams through manipulating the food supply should be considered strictly experimental at this stage. Though it has been demonstrated that juvenile coho salmon populations can be increased during the summer by supplementary feeding, the actual production of coho smolts may ultimately be limited by the physical capacity of the stream to provide them with cover from predation and shelter from freshets during the following winter and spring, prior to seaward migration. Provision of additional overwintering habitat may thus be a prerequisite to increasing smolt production. Careful evaluation, including smolt enumeration, is required to establish the level of benefit to be expected.

16. PREDATOR AND COMPETITOR CONTROL

The effects of predation and competition on stream salmonid production have been difficult to document and quantify. Birds and fish are suspected to be the major predators of juvenile salmonids in streams and estuaries. Among bird predators, the common merganser, belted kingfisher and Great Blue Heron appear to be most important. Several fish species are known to prey heavily on pink and chum salmon fry during their seaward migration from coastal streams. These include two species of sculpins, the coastrange sculpin *Cottus aleuticus*, and prickly scuplin *Cottus asper*, coho salmon and steelhead trout smolts, adult cutthroat trout, and Dolly Varden char. Where spawning beds are composed of relatively coarse gravel, sculpins have been observed to penetrate into the gravel to prey on deposited salmon eggs. In large lakes or reservoirs, and in the larger rivers, the northern squawfish *Ptychocheilus oregonensis*, resident rainbow trout and Dolly Varden can be important predators, particularly of juvenile sockeye and coho salmon.

Adult salmon are exposed to predation during upstream migration and spawning. For example, bears prey on salmon in areas where the fish concentrate, at falls or other obstructions, and on the spawning grounds of the smaller streams. However, bear predation on the spawning grounds may not be as serious as it at first seems, because a high proportion of the salmon taken by bears are exhausted fish which have already completed spawning. River otters are also known to take, occasionally, adult salmon and steelhead holding in pools prior to spawning. Otter and mink have been observed to prey on juvenile salmonids, but the incidence of this activity is not well understood.

The principal competitors of salmonids in streams are other salmonids. Among stream rearing species, there is overlap in requirements for space and food among juveniles. For example, coho juveniles may interact with young steelhead, cutthroat or chinook in their first year of life. However, it appears that because of differences in size, related to time of fry emergence, and different habitat preferences, competition between the species is minimized. In some cases, adult salmon may compete for spawning area. Chum salmon, for example, have been observed to utiline the same spawning beds as earlier spawning pink salmon, thus dislodging and killing a significant portion of the deposited pink salmon eggs. When spawning population densities are high, it is common for late spawning fish to cause mortality of eggs deposited by earlier spawning members of the same species by either digging the eggs from the gravel or jarring the eggs during the sensitive stages following fertilization.

Competition from non-salmonid fish species has not been well documented. Sculpins, which are numerous in coastal streams and also feed on aquatic insects, are potential competitors with salmonids for the insect food resource.

The control of fish species which compete with or prey on non-anadromous salmonids has been commonly applied to Lake situations, but in streams the practice has been limited to a few experiments. Unwanted fish species have been eliminated or reduced by treatment of the water body with *rotenone*, a chemical fish toxicant which is not harmful to warm-blooded animals and has only short-term effects on salmonid food sources such as aquatic insects and plankton. A chemical, *aquoxin*, which is toxic to squawfish and other species of the Minnow family, has also been developed but is not yet approved for use by the control agencies. Following eradication of the unwanted fish population, fish barriers are usually installed (Fig. 16.1) to prevent recolonization by fish from downstream areas.

Where juvenile salmonids are reared at artificially high densities such as in hatcheries and stream-side rearing channels, precautions are taken to exclude potential predators. Fish are prevented from entering such areas by screens at both the intake and outlet of the ponds. Mammalian predators, such as mink and otter, can be excluded

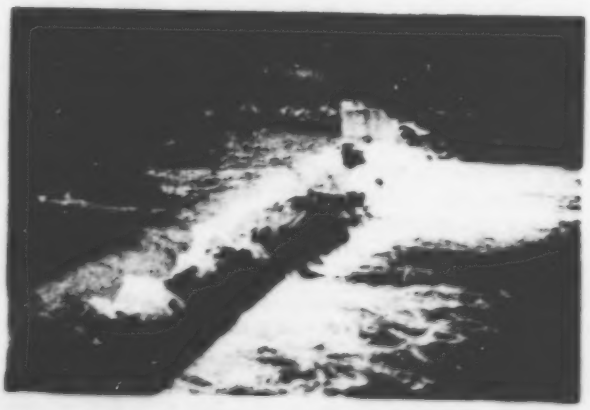


Figure 16.1 A barrier weir used to block the upstream migration of unwanted fish.

Figure 16.2 A series of lines suspended above a salmon rearing channel to discourage bird predators.

by chain-link fencing. Bird predators, such as herons and kingfishers, can be discouraged by the use of overhead netting or criss-crossing lines (Fig. 16.2).

Because streams are essentially open systems, they present significant practical impediments to the control of fish populations. For example, the downstream spread and impact of a fish toxicant is difficult to control. There is also the continuing problem of preventing recolonization by the unwanted fish species. Though the actual impact of predators and competitors on stream salmonids can be high, it has been measured in only a very few cases. The benefits to be gained by implementing control measures are therefore rather uncertain at this time. *Given the limited experience with predator and competitor control in streams, it must be considered a purely experimental approach which, at this stage, must be strictly under the control of the fishery agencies.*

17. PROJECT ASSESSMENT

Due to the complex and varying nature of streams, the impacts and benefits of stream enhancement projects are never totally predictable. It is therefore valuable to estimate what a given project has achieved, and what further work may be needed to ensure that the desired objective is reached. In cases where a project spans several years, an ongoing program of assessment can provide the basis for future improvements which could increase the project's effectiveness.

Four general types of information are useful in project assessment:

(1) the extent to which the enhanced area is used by adult and/or juvenile salmonids;
(2) the production of juveniles or seaward migrants from the enhanced area;
(3) in the case of stream channel and bank improvements, the resultant physical changes to the channel and instream structures; and
(4) adult salmonid returns to the enhanced area, including the catch in freshwater.

In most cases, it will be essential to obtain comparative information both before and after project implementation, but simultaneous comparisons of improved and unimproved stream sections can also be useful.

Adult Salmonids

There are several visual estimating procedures which, given acceptable water clarity, can provide measures of salmonid spawning populations. Visual population estimates are normally conducted at one of two stages: (i) while fish are concentrated in holding pools before spawning; or (ii) during spawning. Counts prior to spawning are most appropriate for species such as steelhead trout and coho salmon, which tend to concentrate in holding pools before distributing themselves throughout the stream system to spawn, often in relatively inaccessible areas. Both species also tend to spawn over a considerable period, usually 2 to 3 months. For populations of chum, pink, sockeye and chinook salmon, whose spawning is generally more concentrated in time and space, visual counts of fish on the spawning grounds usually provide the most satisfactory estimates.

For estimating numbers of fish holding in pools, swimming with wet suit and snorkel will produce the greatest accuracy (Fig. 17.1). On larger streams, two or more swimmers may be needed to cover adequately the total river width. An assistant at streamside is also useful for recording information. Though visual estimates may be obtained from the river bank or from a boat, surface glare and turbulence usually preclude an accurate count of fish holding in pools. Polaroid glasses can assist greatly in reducing glare from the water surface.

As the mature adults of certain species such as steelhead trout are closely associated with cover, their secretive nature makes it difficult to obtain accurate absolute counts. For example, in the Big Qualicum River, a clear and stable stream, snorkel counts could account for only about 25% of the total population actually counted into the stream through a fence. River bank counts of spawning fish are feasible on small to medium sized streams where the water is generally clear. For a given salmon population, timing of spawning is consistent from year to year, with minor variations due to stream flow conditions. Spawning usually takes place over 4 to 6 weeks, and consists of several waves of spawners, each spending 5 to 10 days on the spawning beds. In the case of chum salmon, for example, the average time on the spawning beds would be 7 days. To develop a visual population estimate based on spawner counts, it is necessary to determine: (1) the seasonal pattern of spawner abundance, and (2) their turnover rate, or average time spent on the spawning grounds. Visual counts should therefore be obtained at about weekly intervals over the period of spawning. To determine the time spent on the grounds, it is necessary to observe daily a number of readily identifiable females on their redds. Tagging of females with coloured disk tags can assist in the identification. An example of the visual count method is shown graphically in Fig. 17.2.

Figure 17.1 Swimmers conducting a visual enumeration of adult steelhead trout in a small, spawning stream, using wet suit and snorkel gear.

Coho salmon, steelhead and cutthroat trout, and Dolly Varden, which do not generally spawn at high densities, tend to spawn at night and retreat to the sanctuary of a nearby holding pool during the day. Spawner counts conducted during daylight hours will sometimes underestimate the population. In these cases, a count of redds or spawning nests can provide at least an index or relative measure of female spawner abundance. The observer should be aware, however, that a spawning female salmon or trout may construct more than one redd. A simple count of redds may not, therefore, indicate the actual number of females in the spawning population.

Juvenile Salmonids

Sampling of juvenile populations can be useful to determine the species present in a given area, or to measure

the effect of stream enhancement by comparing population levels before and after the project. However, such a project must only be carried out under the guidance of an experienced fishery biologist or technician. Ability to identify the fish species is also a prerequisite. *Capture of fish for any purpose also requires a sampling permit from the appropriate fishery agency.* When sampling juvenile salmonid populations, it is critically important to avoid damage to the fish in the course of capture and handling.

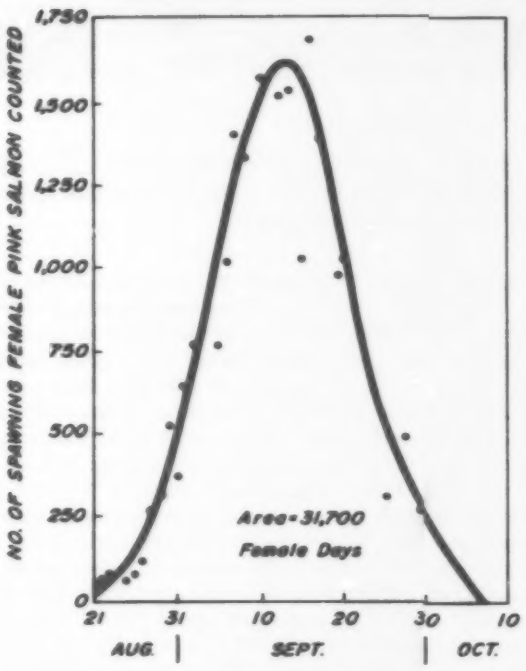


Figure 17.2 Seasonal pattern of pink salmon counts in the Harris River, Southeast Alaska. Estimated numbers of female spawners (2930) equals the total number of spawner-days (area under the curve) divided by the 10.8 day average life span on the spawning grounds (From McNeil, 1964).

The presence and abundance of rearing fish can be measured with a beach seine. Beach seines are generally set in a downstream direction, with the river current. Suitable dimensions of the seine depend on the size of stream. A net 2.5 m deep by 3-6 m long should be adequate in small streams which can be waded. Around tree roots and restricted areas, a short seine (2 m or less) attached on each end to a pole can be effective in reaching fish. The net material should be 13 mm stretched mesh knotless nylon, with a section of 6 mm mesh size if recently emerged fry are to be captured.

It is important to standardize fishing effort when seining to obtain an index of fish abundance. One method is to make successive sets through the sampling area until the catch approaches zero, rest the area for 15 to 20 minutes, and make a further set to ensure that most of the available fish have been captured. A screened live-box or large bucket must be used to retain the catch for counting and release back to the same stream area when seining is completed. Another method is to capture and mark a portion of the fish available, return the marked fish to the stream at random, and seine the area again with more effort. The population can be calculated from the equation $N = MC/R$, where M = number of fish initially marked, C = total number of fish captured the second time, and R = number of marked fish recaptured.

Daytime seining may not be effective, particularly over a rocky stream bottom. Trout, which occupy bouldery, fast-water areas during the day, are known to move into slow, nearshore areas at night. A more representative sample of the population can sometimes be obtained by seining at dusk or at night, with the aid of a gas lantern.

Minnow traps, baited with fish roe or canned fish, can be an effective supplement to seining in some streams because they can capture fish in areas of debris or boulders which cannot be reached with a seine. Snorkel counts have also been used in streams to assess the abundance of coho fingerlings, steelhead parr and resident salmonids.

The seaward migration of salmonids, which takes place mainly at night, can be measured by either total enumeration or by screening a portion of the stream flow with floating gear. On small streams with relatively stable flows and low velocities, a total count of migrants is likely to be most feasible. A simple fence trap, such as the arrangement shown in Fig. 17.3, can be effective. Such a trap should be located at the lower end of a pool or flat reach, in an area where the stream is confined and the water velocity accelerates into a riffle or chute. The screen wings should be set at an angle of less than a 45° to the current, in order to guide fish and debris along the screen and into the sluice. The length of screen must be adequate to accommodate the highest stream flow anticipated. To prevent escape of fish either under or around the ends of of the screen it is essential to seal these areas with plastic sheeting or netting. Periodic releases of marked fish should be made upstream of the fence to check actual trapping efficiency and subsequently correct the total count.

On large streams with substantial fluctuations in flow, floating traps such as the inclined screen shown in Fig. 17.4 are best suited to capturing downstream migrants. Traps of this type are used in various sizes from 30 cm to 120 cm in width, and up to 120 cm in depth. They should be located in areas of relatively high stream velocity (about 1m/sec or more) to reduce the likelihood that downstream migrants will avoid the gear. The proportion of the population sampled with such a partial trapping system is estimated from releases of marked fish upstream of the trap.

Downstream migrant trapping projects can be a useful assessment tool, but they have the potential to cause

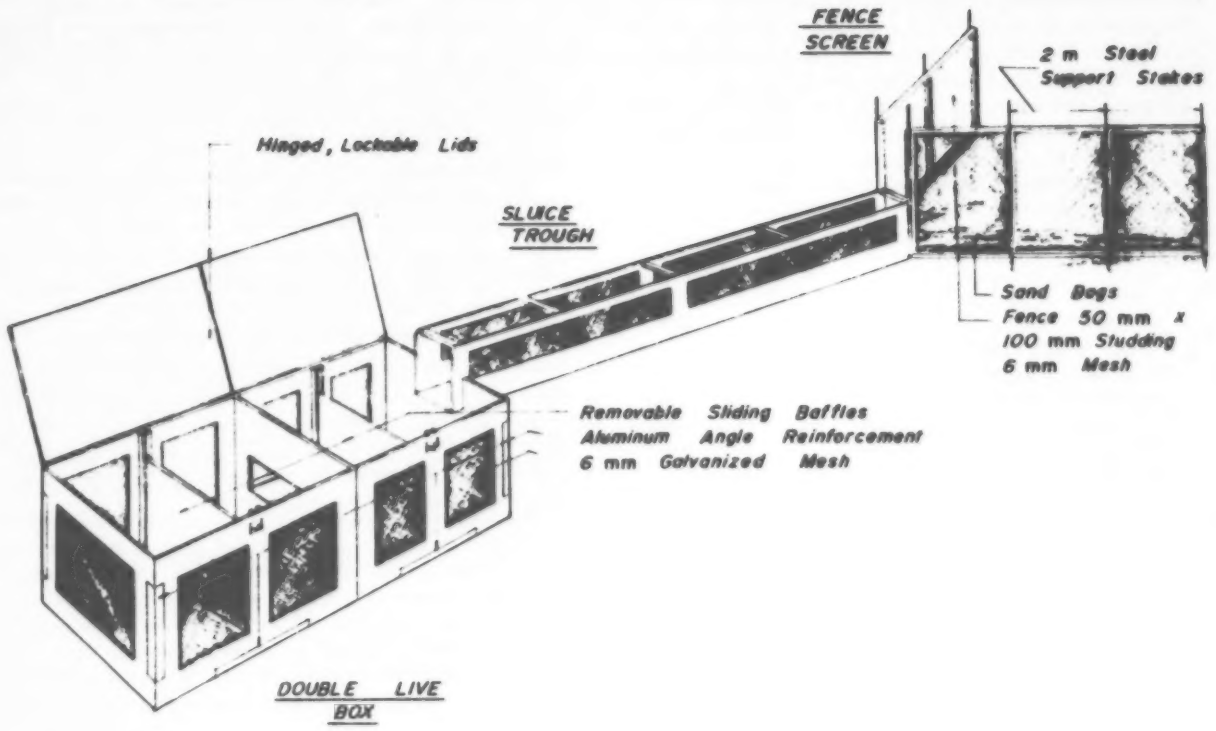


Figure 17.3 *A downstream migrant trapping system for salmonids in small streams. Screens should be placed at an angle of less than 45° to the flow. To obtain adequate water velocity through to the live box, the screen leads should be installed at the lower end of a pool, in an area where the stream accelerates into a steeper riffle section.*

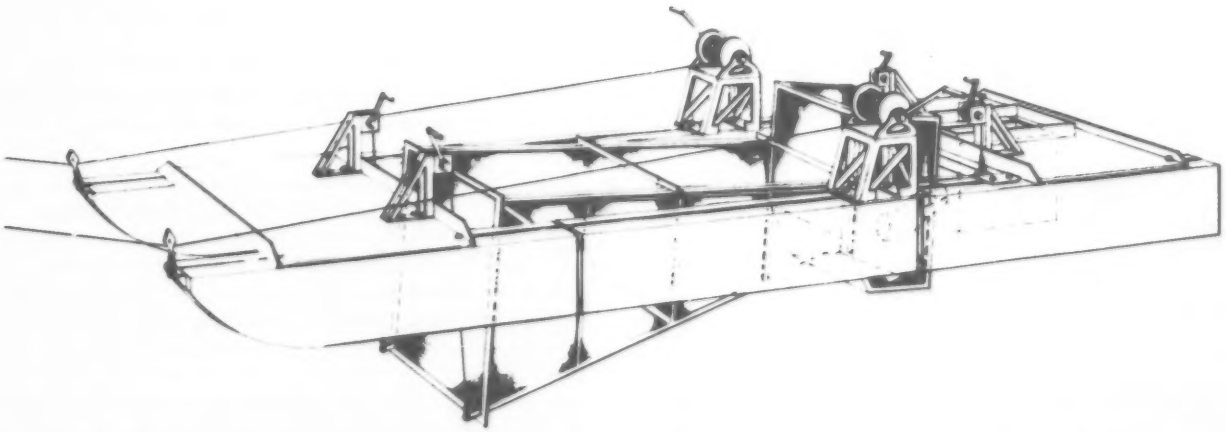


Figure 17.4 *A floating, inclined screen downstream migrant trap capable of screening a 4 ft x 4 ft area of stream. This trap is used for trapping juvenile salmonids on the larger rivers.*

significant fish mortality if proper trapping and fish handling procedures are not followed.

Documenting Physical Changes

The physical effects of stream enhancement activities or installations should be recorded, in order to establish a basis for monitoring seasonal and yearly changes in the improved section and in adjacent upstream and downstream areas. This information is required to determine whether the project has achieved its purpose, how much yearly maintenance is required, and whether modifications are needed. Guidelines for documenting the physical changes for a completed stream enhancement project are:

(1) A series of before and after photographs should be taken at various river flows to record the results of the stream improvements. Each set of photographs should be taken from the same location in order to develop a true comparison between changes that occur with time, river flow and season. The photographs will indicate areas of increased scour, bedload deposition, and possible erosion and movement of the stream devices.

(2) Periodic measurements should be made of pool depth, width and area, relative to a fixed reference point, in order to determine whether the stream devices are effective. For measuring changes in elevations, the fixed reference could simply consist of a nail driven into the trunk or exposed root of a tree.

(3) Timber structures should be checked periodically for rot, and all defective components replaced.

(4) All stream devices should be checked for undermining and detrimental scour which could cause premature breakup of the structure.

(5) Logs, trees, and root wads used to create cover should be checked periodically to ensure they are properly anchored and that decay and physical damage have not destroyed their effectiveness.

Valuable information for planning future stream enchancement projects can be gained by documenting the impact of existing enhancement devices. Such an assessment will not only indicate the success achieved, but will also provide the basis for modifications to improve the effectiveness of future installations.

18. IMPROVEMENTS FOR PUBLIC ACCESS AND EDUCATION

Many people have never seen salmon spawning. They don't appreciate the extent of man's influence on streams, nor do they readily see the need for protecting and restoring fish habitat. However, a high level of interest in fish is evident from the numbers of visitors to large scale government facilities such as hatcheries and spawning channels. It is desirable to balance this exposure to the more artificial aspects of salmonid propagation with the opportunity to view salmonids in natural or enhanced areas along the smaller streams, as has been done at Adams River (Shuswap Lake) and Goldstream River (Vancouver Island). The experience could be both recreational and educational. Though spawning salmon or trout provide the greatest attraction, juvenile coho salmon can also be interesting in a small stream situation, particularly if the viewer can bring fish to the surface with a food attractant such as bread crumbs.

Small streams offer a potential for public education which has yet to be used in any substantive way. In Fig. 18.1 a conceptual layout for a streamside public education area is illustrated. The challenge is to provide opportunities for viewing while avoiding both interference with spawning fish, and destruction of fish habitat. The following guidelines should be followed when providing public access and educational information on a small stream:

(1) Only foot traffic should be allowed along the stream. The entrance to all trails should be well protected to prevent motorized vehicles from destroying the paths and disturbing the fish.

(2) Trails should parallel the stream and provide direct access only at selected locations.

(3) In prime spawning areas trails should be located back from the stream, so the stream is visible but naturally screened by a row of trees and bushes. This will minimize interference with spawning activities.

(4) Direct access to the stream can be located at the pool areas where the fish may be holding but not actively spawning.

(5) Simple rustic bridges can also be constructed at pool areas to provide access across the stream, and to provide a vantage point for viewing a natural spawning area or an enhanced section of the stream (Fig. 11.17)

(6) Parking lots should be located well away from the stream, preferably with a dense barrier of natural trees and vegetation between the parking area and the stream.

(7) A sign with map showing the path relative to the stream channel should be prominently displayed in the parking lot. This sign could include a brief welcome and a general cautionary note warning about interfering with the fish. The map could also show the location of any enhanced areas.

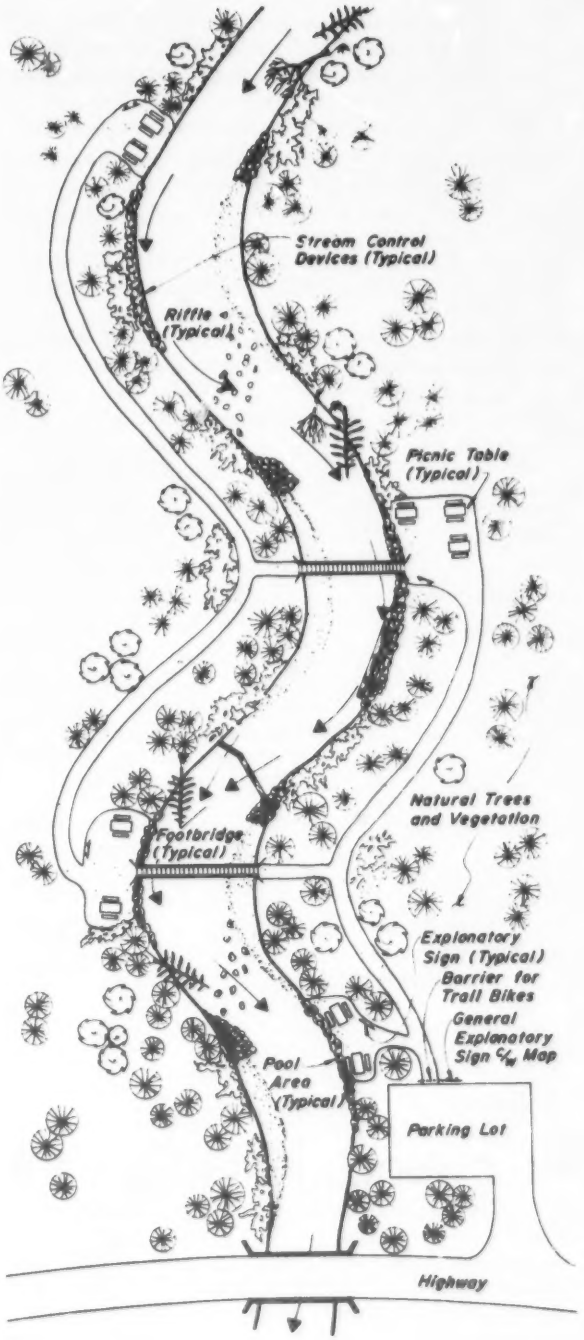


Figure 18.1 Typical trail system to provide public access to improved sections of a stream. Trail bikes must not be allowed on paths. Sensitive stream areas must be buffered by trees and vegetation. Explanatory signs with cautionary remarks should be installed in parking lot and along the trails.

(8) At various locations along the paths, additional signs should be placed to describe the features of each enhanced area in greater detail. Cartoon style drawings could be incorporated to the sign to define the technique as well as convey any message of caution.

To completely restrict access to a section of stream could result in physical damage to both natural cover and man-made devices. Crude paths would develop and trees and other natural foliage could be damaged by the random intrusion of man. At low flows, stream enhancement structures could become *playgrounds* for children, possibly resulting in injury to the child and damage to the facility. In addition, harassment of spawning fish may occur if orderly and controlled access is not available.

19. CONCLUDING REMARKS

This guide is an introduction to the approaches presently available for enhancing the stream environment of anadromous salmonids. As emphasized here, some of the concepts presented do not have a history of application to British Columbia streams. *Such techniques must therefore be applied with caution, under the guidance of experienced fishery agency staff. The results must also be carefully assessed to provide a basis for continuing modification and improvement.* Increased public participation in stream enhancement will lead to greater awareness of the problems confronting anadromous salmonid populations. It is hoped that this guide assists in developing an appreciation of the potential for man's positive influence on the salmonid's environment.

Appendix A

Selected References On Stream Enhancement And Related Topics, Grouped According To Subject Areas Covered In This Guide.

Salmonid Life Histories and Production

Andrew, F.J. and G.H. Geen. 1960. Sockeye and pink salmon production in relation to proposed dams in the Fraser R. system. Intern. Pac. Sal. Fish. Comm., Bull. XI, 259 p.

Burner, C. J. 1951. Characteristics of spawning nests of Columbia River salmon. U.S. Fish & Wildlife Service — Fishery Bulletin 61: 97-110.

Bustard, D.R. and D. W. Narver. 1975. Aspects of the winter ecology of juvenile coho salmon and steelhead trout. J. Fish. Res. Bd. Can. *32*: 667-680.

Chapman, D.W. and T.C. Bjornn. 1969. Distribution of salmonids in streams with special reference to food and feeding, p. 153-176. *In* T.G. Northcote (ed.), Salmon and trout in streams. H.R. MacMillan Lectures in Fisheries, Univ. of British Columbia, Vancouver, B.C.

Carl, G.C., W.A. Clemens and C.C. Lindsey. 1959. The freshwater fishes of British Columbia. Handbook No. 5, B.C. Provincial Museum, 192 p.

Facchin, A. and P.A. Slaney. 1977. Management implications of substrate utilization during summer by juvenile steelhead trout in the South AllouetteRiver. Technical Circular No. 31, B.C. Fish & Wildlife Branch, 19 p.

Hart, J.L. 1973. Pacific fishes of Canada. Fish. Res. Bd. Canada Bull. 180, 740 p.

Hartman, GF. 1965. The role of behavior in the ecology and interaction of underyearling coho salmon and steelhead trout. J. Fish. Res. Bd. Can. *22*: 1035 – 1079.

Mundie, J.H. 1969. Ecological implications of the diet of juvenile coho in streams, p. 135-152. *In* T.G. Northcote (ed.), Salmon and trout in streams, H.R. MacMillan Lectures in Fisheries, Univ. of British Columbia, Vancouver, B.C.

Scott, W.B. and E.J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Bd. Canada Bull. 184, 966 p.

Stuart, T.A. 1964. The leaping behaviour of salmon and trout at falls and obstructions. Dept. of Agriculture and Fisheries for Scotland, Edinburgh, 42 p.

Withler, I.L. 1966. Variability in life history characteristics of steelhead trout along the Pacific Coast of North America. J. Fish. Res. Bd. Can. *23*: 365-393.

The Stream Ecosystem

Andrews, W.A. 1972. A guide to the study of freshwater ecology. Prentice-Hall, Scarborough, Ontario. 182 p.

Cummins, K.W. 1974. Structure and function of stream ecosystems. Bio-Science *24* (11): 631-641.

Hynes, H.B.N. 1970. The ecology of running waters. University of Toronto Press, 555 p.

Mundie, J.H. 1974. Optimization of the salmonid nursery stream. J. Fish. Res. Bd. Can. *31*: 1827-1837.

Habitat Impairment

Bakke, B.M. 1977. Grazing is destroying our fish. Salmon Trout Steelheader Magazine, Feb. – Mar. 1977: 31-34.

Elser, A.A. 1968. Fish populations of a trout stream in relation to major habitat zones and channel alterations. Trans. Amer. Fish. Soc. *97*: 389-397.

Gunderson, D.R. 1968. Floodplain use related to stream morphology and fish populations. J. Wildl. Mgmt. *32*: 507-514.

Hooton, R.S. and D.S. Reid. 1975. Impact of stream channelization on fish and wildlife. B.C. Fish & Wildlife Branch, Victoria, 15 p.

Krygier, J.T. and J.D. Hall (eds.) 1971. A symposium — Forest land uses and stream environment. Oregon State Univ., Corvallis, 252 p.

Moring, J.R. and R.L. Lantz. 1975. The Alsea watershed study: Effects of logging on the aquatic resources of three headwater streams of the Alsea River, Oregon, Parts I and II. Fishery Res. Rept. No. 9, Oregon Dept. Fish & Wildlife, Corvallis.

Narver, D W. 1972. A survey of some possible effects of logging on two eastern Vancouver Island streams. Fisheries & Marine Service, Tech. Rept. No. 323, 55 p.

Servizi, J.A., D.W. Martens and R.W. Gordon. 1970. Effects of decaying bark on incubating salmon eggs. Intern. Pac. Sal. Fish. Comm., Prog. Rept. No. 24, 28 p.

White, R.J. 1973. Stream channel suitability for coldwater fish, p. 7-25. In wildlife and water management: striking a balance. Soil Conserv. Soc. of America, Ankeuy, Iowa.

Fishways and Fish Screens

Clay, C.H. 1961. Design of fishways and other fish facilities. Dept. of Fisheries of Canada, Ottawa, 301 p.

Dane, B.G. 1978. A review and resolution of fish passage problems at culvert sites in British Columbia. Fisheries & Marine Service, Tech. Rept. No. 810, 126 p.

Slaney, P.A. 1977. An evaluation of a diversion screen design and an assessment of fish losses in irrigation diversions of Loon Inlet Creek, British Columbia. Fisheries Management Rept. No. 68, B.C. Fish & Wildlife Br., Vancouver, 15 p.

Salmonid Culture

Bams, R.A. and K.S. Simpson. 1977. Substrate incubators workshop — 1976: report on current state of the art. Fish. Mar. Serv. Tech. Rept. No. 689.

Leitritz, E. 1976. Trout and salmon culture. Fish Bulletin No. 107, California Dept. Fish and Game. (Order from Office of Procurement, Documents Section, P.O. Box 20191, Sacramento, California, 95820. Price $2).

McNeil, W.J. and J.E. Bailey. 1975. Salmon rancher's manual. (May be obtained free of charge from Northwest Fisheries Center, Auke Bay Laboratory, P.O. Box 155, Auke Bay, Alaska, 99821).

Zimmer, P.D. 1964. A salmon and steelhead egg incubation box. Prog. Fish Culturist *26:* 139-142.

Physical Processes in Streams

Chow, Ven Te. 1959. Open channel hydraulics. McGraw Hill. New York.

King, H.W. and E.F. Brater. 1963. Handbook of hydraulics. McGraw Hill, New York.

Leopold, L.B. and W.B. Langbein. 1966. River meanders. Sci. Amer. *214* (6): 60-70.

Vaux, W.G. 1968. Intragravel flow and interchange of water in a stream bed. U.S. Fish & Wildlife Service — Fishery Bulletin 66 (3): 479-489.

Stream Habitat Improvement

Forest Service. 1969. Wildlife habitat improvement handbook. U.S. Dept. of Agriculture. Publ. No. FSH2609.11.

Hunt, R.L. 1978. Instream enhancement of trout habitat, p. 19-27. *In* Proceedings of a Symposium on Wild Trout Management. California Trout Inc., San Francisco.

Ward, B.R. and P.A. Slaney. 1979. Evalustion of instream enhancement structures for the production of juvenile steelhead trout and coho salmon in the Keogh River. B.C. Fish and Wildlife Branch, Fisheries Management Rept. (in press).

White, R.J. and O.M. Brynildson. 1967. Guidelines for management of trout stream habitat in Wisconsin. Wisconsin Dept. Nat. Resources Tech. Bull. No 39, 64 p.

Erosion and Sediment Control

B.C. Ministry of Mines and Petroleum Resources. 1977. Guidelines for coal and mineral exploration. Inspecton and Engineering Division, Victoria, 61p.

Federal Water Pollution Control Administration. 1970. Industrial waste guide on logging practices. U.S. Dept. of Interior, Portland, Oregon. 40 p. + illustrations.

U.S. Environmental Protection Agency. 1976. Erosion and sediment control–surface mining in the eastern U.S. Technology Transfer, EPA-627/3-76-006.

Wilford, D.J. 1975. A selected annotated bibliography of road cut and fill revegetation. Reprinted by the Research Div., B.C. Forest Service, 20 p.

Increasing the Food Supply

Mason, J.C. 1976. Response of underyearling coho salmon to supplemental feeding in a natural stream. J. Wildl. Mgmt. *40:* 775-788.

Stockner, J.G. and K.R.S. Shortreed. 1978. Enhancement of autotrophic production by nutrient addition in a coastal rainforest stream on Vancouver Island. J. Fish. Res. Bd. Can. *35:* 28-34.

Predation and Competition

Eschmeyer, P.H. (ed.) 1975. Rehabilitaton of fish populations with toxicants: a symposium. Amer. Fish Soc. Publ. No. 4, 74 p.

Moyle, P.B. 1977. Are coarse fish a curse? Fly Fisherman Magazine *8* (5): 35-39.

Project Assessment (Fish Populations)

Armstrong, R.W., and A.W. Argue. 1977. Trapping and coded wire tagging of wild coho and chinook juveniles from the Cowichan River system, 1975. Fish Mar. Serv., Tech. Rept. PAC/T-77-14, 58p.

Bagenal. T.B. (ed.) 1978. Methods for assessment of fish production in fresh waters. Intern. Biological Programme Handbook No. 3, Blackwell Scientific Publications, Oxford, 384 p.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries & Marine Service, Bull. 191, Ottawa, 382 p.

General References

Migel, J.M. (ed.). 1974. The stream conservation handbook. Crown Publishers, Inc. 242 p.

Parkinson, E.A. and P.A. Slaney. 1975. A review of enhancement techniques applicable to anadromous gamefishes. B.C. Fish and Wildlife Branch, Fisheries Management Report No. 66, 100 p.

Appendix B
Distinguishing Features of Adult and Juvenile Anadromous Salmonid Species

The following diagrams are a guide to identifying the species of British Columbia salmon and anadromous trout in freshwater. The illustrations are arranged with distinguishing features of the fish indicated by a marker, and a description of those features on the opposite page.

The material in this appendix was originally presented in the following publication:

Ellis. D.V. (ed.). 1977. Pacific Salmon — Management for People. Western Geographical Ser., Vol. 13, Univ. of Victoria, 320 p.

The authors are grateful to Dr. Ellis for permission to reproduce the material for this appendix.

Adults

Sockeye Salmon

Migrating — dorsal surface dark, greenish-blue with fine black specks; body spots absent; ventral surface silver.

Male — head green; forward dorsal surface forms a hump; body red.

Female — head green; body red; side of body with broad, dark stripe.

Chinook Salmon

Migrating — dorsal surface greenish-blue to black; moderately large, irregular black spots on back, upper sides, dorsal fin and both lobes of caudal fin.

Male — forward part of body may deepen considerably; body spots present and caudal fin spotted on both lobes (as in migrating form).

Female — body dark; spots on body and caudal fin (as in migrating form).

Cutthroat Trout

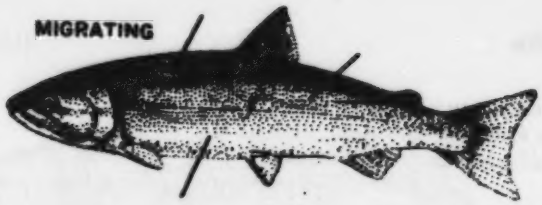
Body spots abundant both above and below lateral line; greenish-blue on back; caudal fin spotted; red dash along inner edge of lower jaw.

Rainbow (Steelhead) Trout

Metallic blue on dorsal surface; silvery on sides; black spots on back, dorsal and caudal fins; dorsal, anal and ventral fins with white to orange tips; opercula pink; red band on side of body (more pronounced in mature, spawning fish).

SOCKEYE

MIGRATING



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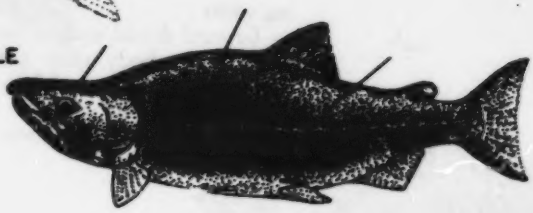
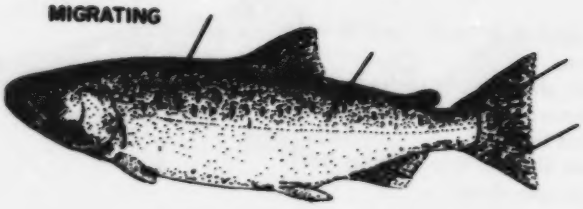


FEMALE

CHINOOK

MIGRATING



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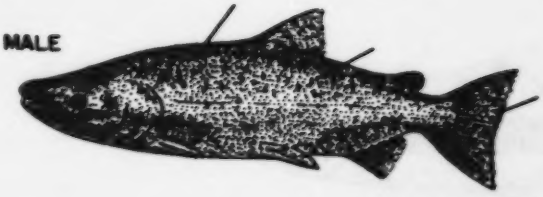

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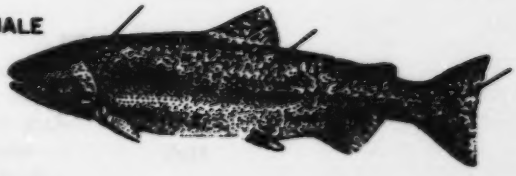
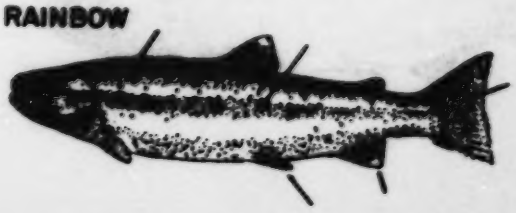


CUTTHROAT

RAINBOW



Adults

Pink Salmon

Migrating — Numerous large black, oval spots on upper sides, back and all caudal fin; dark stripe on sides of body; ventral surface glaring white.

Male — forward dorsal surface forms a prominent hump; body spots present; broad, dark stripe on side; caudal fin spotted; ventral surface glaring white.

Female (not illustrated) — resembles migrating form, but darker.

Chum Salmon

Migrating — usually similar to male and female spawning forms.

Male — body spots absent; side of body bears vertical patterns of black, yellow and purple; prominent teeth.

Female — body spots absent; side of body bears broad, dark purple stripe.

Coho Salmon

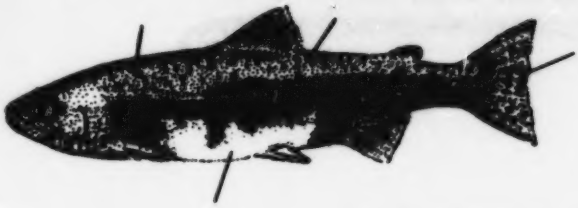
Migrating — nostrils white; black spots on back and upper lobe of caudal fin; dorsal surface a dark, metallic blue.

Male — nostrils white; body colour very dark; side of body with broad, red stripe; caudal fin spotted on upper lobe only.

Female (not illustrated) — resembles migrating form but overall colour darker, with broad red lateral stripe.

PINK

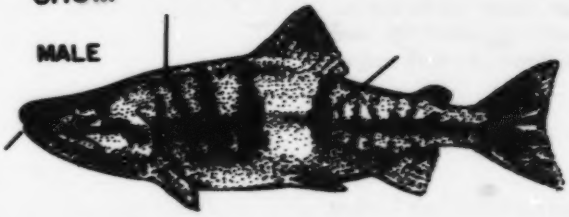
MIGRATING



MALE

CHUM

MALE



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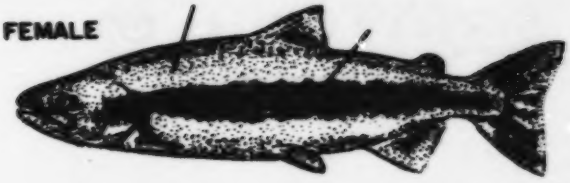
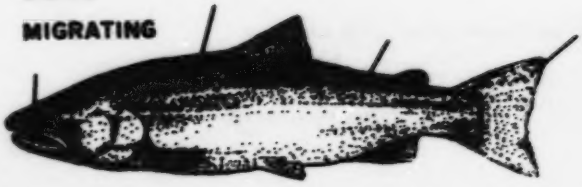
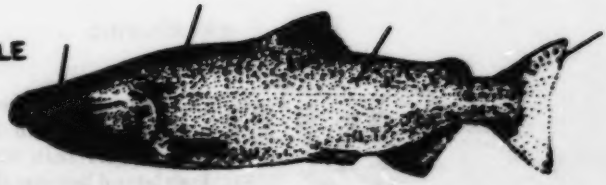


COHO

MIGRATING



MALE



Juveniles

Pink Fry

Length 3 – 3.5 cm; no parr marks (dark vertical bars); dorsal surface dark green; ventral surface and sides silver.

Chum Fry

Length 3.5 – 4 cm; slender parr marks above lateral line; dorsal surface dark green; ventral surface and sides silver.

Coho Fry

Early —length 3 – 4 cm; dorsal fin with conspicuous white leading edge followed by dark stripe; parr marks prominent, above and below lateral line; anal fin with extended tip, and white leading edge followed by dark stripe.

Late — length 5 – 8 cm; dorsal fin with black leading edge and white tip; parr marks prominent; anal fin with extended tip and white leading edge.

Sockeye Fry

Length 2 – 3 cm; green back; parr marks short, oval and mainly above lateral line.

Chinook Fry

Length 4 – 8 cm; dorsal fin with dark leading edge and white tip; adipose fin with dark trailing edge; parr marks prominent, longer than vertical diameter of eye; dark areas along lateral line equal to or greater than light areas; anal and pelvic fins with white leading edges.

PINK FRY

CHUM FRY

EARLY COHO FRY

LATE COHO FRY

SOCKEYE FRY

CHINOOK FRY

Juveniles

Cutthroat Fry

Length 2 – 4 cm; parr marks prominent; dorsal fin with white tip on three rays and spotted; adipose fin with dark edge; white leading edges on anal and pelvic fins.

Rainbow (Steelhead) Fry

Length 2 – 4 cm; forward dorsal surface with parr-like marks; parr marks prominent; dorsal fin with white tip on six rays and spotted; adipose fin with continuous dark edge; white leading edges on anal and pelvic fins.

Coho Smolt

Length 8 – 13 cm; dorsal surface brown or green; dorsal fin with white tip and dark patch; parr marks faint or absent; caudal fin with dark patch at tip of each lobe; anal fin slightly extended, with white tip; ventral surface silver.

Sockeye Smolt

Length 6 – 13 cm; dorsal surface brown or green; parr marks small, irregular and faint or absent; ventral surface silver.

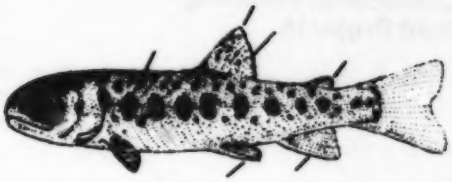
Cutthroat Juvenile

Length 7 – 15 cm; body spots abundant; spotting below lateral line, equally heavy on anterior and posterior halves of body; dorsal fin with white tip over three rays and spotted; caudal fin spotted; anal and pelvic fins with white tips; parr marks may be present.

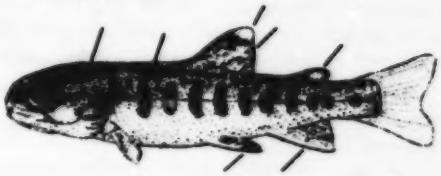
Rainbow (Steelhead) Juvenile

Length 7 – 15 cm; body spots abundant; dorsal fins with white tip over 6 rays and spotted; caudal fin spotted; anal and pelvic fins with white tips; pink or red stripe on side of body; parr marks may be present.

CUTTHROAT FRY



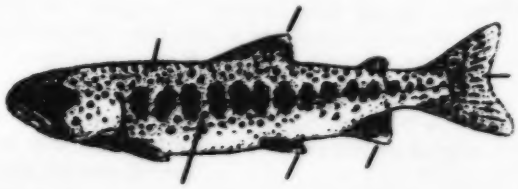
RAINBOW FRY



COHO SMOLT

SOCKEYE SMOLT

CUTTHROAT JUVENILE



RAINBOW JUVENILE

Appendix C

Check List of Factors to Consider in Planning Stream Enhancement Projects

Project Purpose

— what the project is intended to achieve, and what salmonid species are involved.

Project Area

— include map showing stream and major tributaries.

Name of Stream(s)

Barriers to adult salmonid migration

Location of Stream — location on map
— description
— length of stream above barrier

Length of Stream

Average Width of Stream

Salmonid Stocks

Species Estimated Population Size

Location of spawning areas

— describe and indicate on map.

Effects of Land and Water Use on the Stream

Existing Impacts

— the reason, ie. water diversion. pollution, channel modification, etc.

— locate problem areas on map.

Probable Future Impacts

— what plans for future development that could affect salmonid habitat are known?

Salmonid Habitat Limitations

Juvenile Rearing

— explain your reasons for your assessment

Spawning

— explain reasons for your assessment

Access

— describe nature of obstruction(s).

Appendix D
Glossary of Technical Terms

Alevin. Stage of development of the salmonid embryo from hatching to absorption of the yolk sac. The yolk sac is generally the sole source of energy at this stage.

Anadromous. Of a stock or species of fish which reproduces in freshwater and migrates to salt or brackish water to rear for a portion of its life, usually achieving most of its growth in saltwater.

Bankrun Gravel. Natural unprocessed well graded sand and gravel which can be excavated directly from an open pit or existing embankment.

Barrier Dam. A low dam across a stream, used to divert water or to guide fish to the entrance of a fishway. May also be used to block upstream fish migration.

Block-and-Tackle. A system of pulleys and ropes used to pull or lift an object. The amount of effort required to lift or move heavy object can be reduced several fold by utilizing a block-and-tackle.

Broodstock. Fish collected and spawned artificially for purposes of artificial propagation or transplantation.

Carrying Capacity (biological). The maximum average number of a given organism that a stream or section of stream can maintain under a given set of conditions and over a specified period. Carrying capacity may vary from season to season or from year to year.

Choker. A short rope or wire normally fitted with a locking socket assembly which allows one end of the cable to be readily looped around an object and easily removed once tension on the cable is relaxed.

Cover. An area of shelter in a stream that provides aquatic organisms with protection from predators and/or a place to rest and conserve energy.

Detritus. Organic debris from decomposing plants and animals.

Ecosystem. An ecological system or unit that includes living organisms and nonliving substances which interact to produce an exchange or cycling of materials.

Embryo. For salmonid fish, the stage of development between egg fertilization and absorption of the yolk sac, at which time the emerging fry begins to seek external sources of food.

Energy Dissipation. The loss of kinetic energy of moving water due to bottom friction, pools, large rock, debris and similar obstacles that impede flow.

Eyed Egg. The stage of embryonic development when the body shape and eyes have formed within the egg.

Feather and Wedges. Steel hand tools for splitting rock. The complete tool consists of two thin steel wedges which insert into a predrilled hole in the rock. A third wedge is forced in between the first two wedges to cause the rock to split.

Fecundity. General term used to describe the number of eggs produced. Fecundity of an individual female may vary according to species, stock, size and age.

Freshet. A rapid rise in river discharge and level caused by heavy rains or melting snow.

Gabion. A galvanized wire basket with a removable top. The basket, filled with selected stones, is used to stabilize banks to control erosion in streams and to prevent stream gravel from shifting.

Gallery. The area of a water intake structure behind the trash rack, where water is distributed across the face of screens which prevent fish and small debris from entering the water system.

Hydraulic Jump. An abrupt, turbulent rise in the water level of a flowing stream, normally occurring at the transition from shallow, fast flow to deeper and slower flow.

Hydrologic. Refers to water in all its states, and its properties, distribution and circulation through the hydrologic cycle.

Invert. Refers to the bottom, inside surface of a pipe or conduit. Occasionally used to refer to the bottom or base elevation of a structure.

Morphometry. The form or shape of a lake or stream, including the contour of the bottom.

Periphyton. Various types of algae growing on submerged surfaces, firmly or loosely attached.

Point Bar. A deposit of sand, gravel or other material on the inside of a stream bend, which causes some obstruction to the flow.

Pool. That portion of a stream where the water is relatively deep and slow moving.

Revetment. A facing of stone or broken rock pieces placed on a stream bank to prevent or minimize erosion from high velocity flow.

Riffle. A shallow, rapid section of stream where the water surface is broken into waves by obstructions wholly or partly submerged.

Run. A stream section of varying depth with moderate velocity and surface turbulence. Intermediate in character between a pool and a riffle.

Salmonid. Refers to a member of the fish family classed as Salmonidae, including the salmons, trouts, chars, whitefishes and grayling.

Seston. The total mass of living and non-living matter suspended in the water.

Smolt. A seaward migrating juvenile salmonid which is silvery in color, has become thinner in body form and is physiologically prepared for the transition from fresh- to saltwater. The term is normally applied to

the migrants of species such as coho, sockeye and steelhead which rear in freshwater for a period before migrating to sea.

Species. The smallest unit of plant or animal classification commonly used. Members of a species share certain characteristics which differ from those of other species, and they tend not to interbreed with other species.

Standing Wave. A turbulent condition in a stream which produces a fixed wave pattern at a specific location. Standing waves are often caused by two similar waves travelling at the same time in opposite directions.

Stock. A population of one species of fish which inhabits a particular stream and tends to spawn at a place or time separate from the other stocks.

Talus Slope. A sloping mass of rock fragments which has been dislodged from a mountain side for cliff due to the process of weathering. The rock fragments accumulate faster than the forces of erosion are able to remove them or reduce them to smaller particles.

Thalweg. The path of maximum depth in a river or stream. This path normally follows a meandering pattern, back and forth across the channel.

Training Wall. A low dam which is normally constructed parallel or at an angle to the river banks to direct flow in a specific direction.

Transport Velocity. The velocity of flow required to maintain particles of a specific size and shape in motion along the stream bed.

Weir. A low dam or fence constructed across a stream or river primarily to control water levels or to divert water into another facility.

Year Class. The fish spawned or hatched in a given year.